

THE DESIGN AND CONSTRUCTION  
OF  
CONCRETE PAVEMENTS

A Thesis

Submitted for the Degree of  
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## THE DESIGN OF CONCRETE PAVEMENTS

### Introduction

This paper is prepared to bring forth the results of tests, investigation and experience in pavements which have not previously been collected into one paper. It is primarily written for the highway engineer and his engineering assistants. The section of design is, of necessity, of a technical nature and probably of little interest to other than technical men.

No attempt has been made to describe every construction operation in detail. Instead, attention has been confined to things which are not well known or which observation indicates need to be emphasized if the quality of concrete pavements is to be improved.

### REFERENCES:

- Report of Chicago Street Traffic Survey.
- Journal of Western Society of Engineers.
- Engineering News-Record.
- Proceedings of Highway Research Board.
- Public Roads.
- Purdue University Experiment Station Bulletin.
- Proceedings of American Concrete Institute.
- U. S. Dept. of Agriculture Bulletin
- American Society for Testing Materials

## THE DESIGN OF CONCRETE PAVEMENTS

### W I D T H

Pavement width is figured from curb face to curb face or from slab edge to slab edge when there are no curbs. The width needed depends upon the traffic to be carried, which is influenced by the character, future possibilities and present uses of the district through which the pavement passes, the height of buildings and the districts which the street connects, and for roads, the proximity of cities or the amount of through traffic.

It is customary to allow a 10-foot width for each lane of anticipated traffic and an 8-foot lane for parking parallel to the curb. A 9-foot traffic lane for moving traffic and 6 feet for each line of parked vehicles has been tried, but it make close quarters and promotes accidents. Vehicles parked at an angle to the curb should be given an 18-foot lane; this can be divided into a 10-foot lane for moving vehicles and an 8-foot parking space when wider roadway is needed. These widths are considered both the maximum and the minimum desirable. Narrower lanes cause accidents by crowding. Wider lanes cause accidents because cars try to squeeze between two lines of moving vehicles. Allow 2-feet next to curb as non-travelled space on streets, where parking is prohibited, because drivers cannot be persuaded to drive closer than that to curbs. Unless this extra width is provided for the outer lanes, cars will use or overlap the central lanes on multiple lane streets.

2

For a street bordered by single family homes and carrying only light local traffic, use a 26-foot pavement which provides one 10-foot traffic lane and two 8-foot parking lanes. When cars pass on such a street, one must turn into the parking space. Streets near a church or neighborhood theater must be wider unless parking space is provided outside the curb and the street proper is kept entirely clear of parked cars. Streets adjacent to boulevards on which no parking is allowed should have at least two traffic and two parking lanes since the parking space may be filled by cars which would normally park on the boulevard. The same thing is true of streets near the business district, even though those streets would not otherwise require so much pavement. Wider streets are recommended except for little used side streets. The 26-foot width proves dangerous if there is more than an occasional vehicle.

For residential streets bordered by apartments or duplex houses and carrying only local traffic, or for any other light traffic streets where both parking lanes are likely to be filled with cars, use a 36-foot pavement. This provides for two traffic lanes and two parking lanes. Two cars can pass between two parked cars on pavements as narrow as 30 feet but the narrower width promotes both accidents and traffic congestion, especially at night. Therefore widths between 26 feet and 36 feet are not recommended.

For business streets where store and office buildings do not exceed a height of 4 stories, and other streets carrying heavy traffic, use four 10-foot and two 8-foot lanes. If angular parking is to be allowed, add 2- feet to this width.





City Street With Four 10-Foot Lanes and Two 8-Foot Lanes.

Six 10-foot and two 8-foot lanes are needed on streets carrying very dense traffic. For angular parking, add 20 feet as before, making a 96-foot pavement. On very wide streets which may some day require a wider pavement or a street car line, a center zone is sometimes left unpaved to be planted with grass, flowers or shrubs. The pavement on each side is made wide enough for half the expected traffic with an allowance for a 2-foot untravelled strip along the edges of the center zone and an 8-foot parking lane along each outside curb.

If street car tracks are expected, the zone should be wide enough to accomodate the tracks. That width varies somewhat, but is usually 9-feet per track. If no tracks are expected, the zone should be a width which will give the pavement an even number of traffic lanes when the zone is paved.

Narrower zones are sometimes built to add beauty to the street, separate traffic or reduce paving cost without changing curb lines. The two additional lines of curb required are sometimes more expensive than pavement, for the entire width of the center zone.

The street width around a circular zone in the center of an intersection is theoretically 25 percent of the sum of the width of all intersecting streets. But because not all the intersecting streets carry maximum traffic at the same time, circles of less width are carrying traffic satisfactorily.

Where there are street railway tracks, lane widths should be figured from the outside edge of street cars. If safety landing spaces are provided for street car passengers, a corresponding additional width should be allowed for streets on which parking is prohibited. Where parking is allowed, it can be prohibited near the safety landing spaces and no additional

width will then be necessary. A width of at least 9-feet is essential between the safety island and the curb and a distance of 4 or 5 feet is desirable from the side of the street car to the outer edge of the safety zone.

The Committee on Traffic Analysis of the Highway Research Board, recommends an even number of traffic lanes, but adds that 3-lane pavements have been found satisfactory where pronounced peak loads have to be carried in alternate directions. That is frequently the case on roads and streets leading to the business districts of large cities. There, most of the traffic is in-bound in the morning and out-bound at night, so the direction of traffic in the center lane is reversed morning and evening to care for maximum traffic. The 3, 5 or 7-lane pavement, when used, requires lane marking and traffic control by police.

A traffic lane width of 10 feet is recommended by all engineering groups dealing with highway design in preference to the 9-foot lane which has been in common use. It is claimed that pavements 20 feet wide are actually cheaper in the end, than narrower slabs because shoulder maintenance charges are less and that traffic movement is speeded up and accidents are decreased.

One-lane or single-track highways are frequently built in districts where traffic is light and where money is not available for full-width construction. Single-track slabs have proved highly satisfactory for such roads. They are usually built with one-edge of the slab on the center line of the right-of-way so that if they are ever widened, the pavement will be properly centered. Sometimes short full-width sections to be used in passing are provided at quarter or half-mile intervals, but more frequently a continuous gravel or macadam

shoulder is constructed to accommodate passing vehicles.

Usually the one lane slab is put upon the right hand side of the road for the direction in which it is expected the greater number of loaded vehicles will travel, so that they will not be forced to turn off the pavement.

For uninterrupted traffic, the theoretical maximum number of vehicles which one traffic lane will discharge per hour is given by the formula:

$$N = \frac{5280V}{D}$$

When N = number of vehicles

V = velocity in miles per hour

D = distance in feet from the center of

one vehicle to the center of the next.

To use this formula, we need to know how close together cars can travel without danger of rear end collision, in case the forward car is stopped suddenly. This depends on (1) the time it takes the driver to put the brakes into action after he discovers the emergency and (2) the distance in which a car can stop. The latter depends on the friction between tires and pavement and the speed at which the car is traveling. To put this into a formula, we assume the following:

a = deceleration in ft. per sec. per sec.

F = total deceleration force in lbs.

f = coefficient of friction between tire and pavement.

W = weight of car in lbs.

g = acceleration due to gravity = 32.2 ft. per sec. per sec.

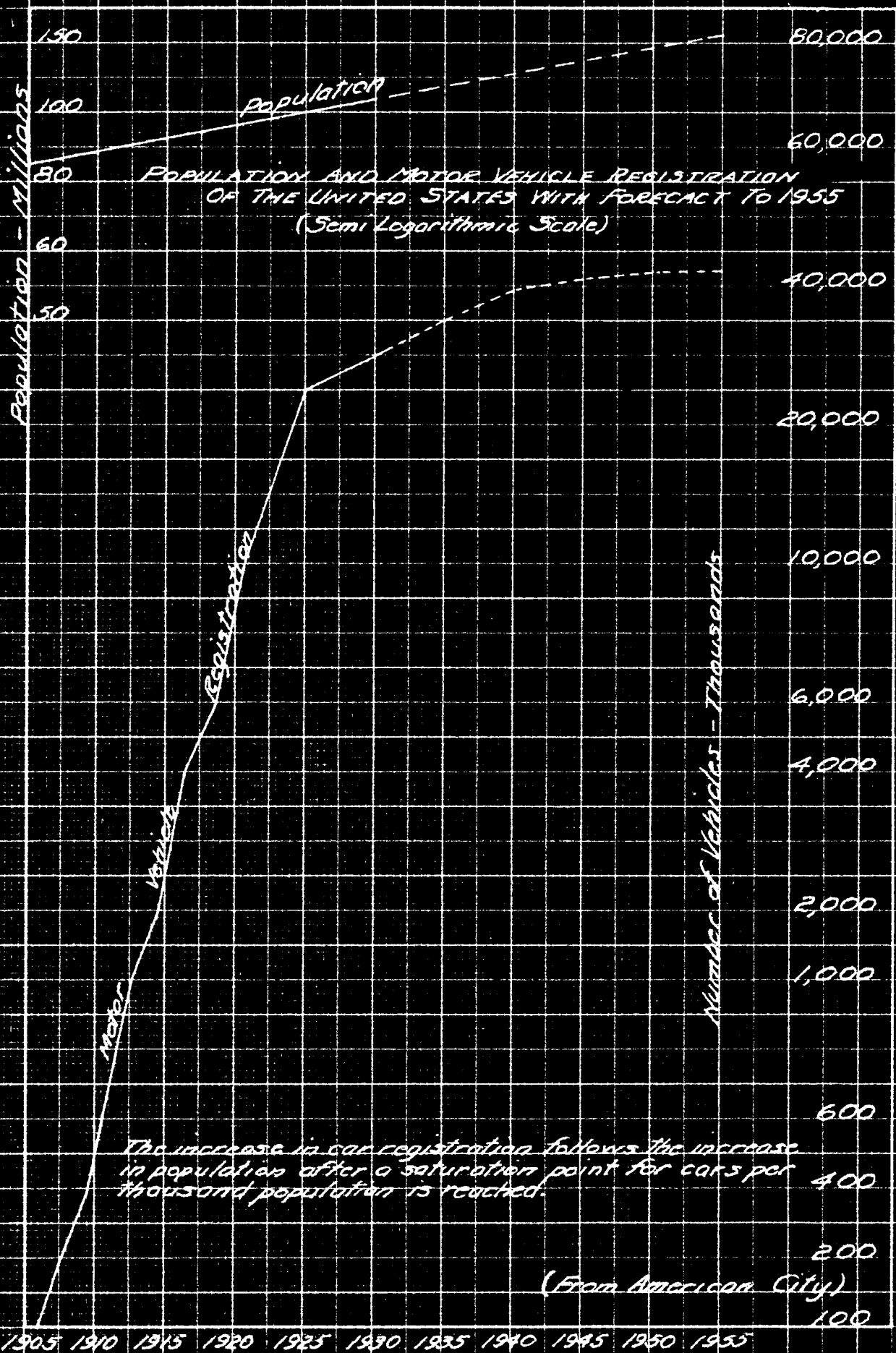


Fig. 1

$$M = \text{mass of car} = \frac{W}{g}$$

$V$  - speed of car in ft. per sec.

From tests conducted by the U. S. Bureau of Standards, the following coefficients of friction have been selected as fairly representative of various types of pavement surfaces:

PAVEMENT	COEFFICIENT OF FRICTION
Concrete, dry, rough surface texture	0.90
" wet	0.76
Asphalt, dry	0.82
" wet, slightly oily	0.54
Macadam, loose	0.60

For a car with 4-wheel brakes, each operating equally and each capable of sliding the wheels, the formula for deceleration is:

$$a = \frac{F}{M} = \frac{Wf}{M} = \frac{Mgf}{M} = gf$$

For dry concrete the deceleration would be at the rate of 29 ft. per sec. per sec. and for wet concrete it would be 24 ft. But it is not correct to assume that the average car has perfectly adjusted brakes. Assume instead, that under average conditions, the deceleration will be 20 ft. per sec. per sec. Also assume that there is an interval of one second from the time the average driver sees an emergency until breaking begins. In that time, the car will travel ( $V$ ) ft. Assuming a length of car of 15 ft. the formula for "D", the safe distance from center to center of car, then becomes:

$$D = V + 15 + \frac{V}{a} \times \frac{V}{2} = V + 15 + \frac{V^2}{2a}$$

Putting this value for D in the formula for N and solving for various vehicle speeds, we find the discharge per traffic lane to be from 1500 to 1700 cars per hour at speeds of 15 to 25 miles

per hour.

This theoretical analysis assumes that the front car stops instantly, as it would if it were in a head-on collision. If it used its brakes to come to a stop, then the safe distance between cars would be the distance which the second car would travel before its driver discovered that the front car was coming to a stop.

The closeness with which the actual maximum discharge agrees with the theoretical depends upon the degree with which the individual driver approaches this safe distance and upon traffic delays.

When there is more than one traffic lane in each direction, the outer lane should carry the slower vehicles. With the two lane pavement, these slower vehicles would determine the speed of all vehicles during maximum congestion. For a 4-lane highway, during maximum congestion, the outer lanes of traffic would still move at the speed of the slowest vehicle while the speed of the inner lines would be increased appreciably. The number of vehicles discharged does not change much for speeds between 15 and 20 miles per hour, so it is doubtful if the increased speed would have much effect on the total number of vehicles actually handled. Some investigators claim that the 4-lane highway will carry less than double the traffic of the 2-lane, but the above discussion indicates that doubling the width should at least double the capacity.

The Michigan Avenue bridge over the Chicago River has six traffic lanes. It carries autos and busses. A traffic census in 1926 (Report of Chicago Street Traffic Survey) showed that in the hour from 4:30 to 5:30 p.m., 3,619 vehicles were carried by the three north-bound traffic lanes, or an average of 1,206 cars per lane per hour. The inner lane carried 1,552 of these cars, or 43 percent.

It is impossible to tell from a census exactly what traffic a street will have to carry after it is improved, but such a census does aid in making an intelligent guess. A concrete pavement will attract vehicles from a good distance on every side of it because of its smooth riding qualities.

The calculations and traffic counts given, are for maximum traffic/ That brings on the possibility of collision, traffic tie-ups and all the dangers, time losses and annoyances of traffic congestion. For normal traffic, which is assumed to be that which the road will carry when vehicles move at the average speed of 25 m.p.h., a 2-lane country road can be estimated to carry 1,000 vehicles per hour and a 2-lane highway in the suburban area 800 to 1,000 per hour. A very high proportion of trucks, busses or other slowly moving vehicles will decrease these capacities.

There is considerable difference of opinion concerning the capacity of multiple lane roads but one of the best comes from T. H. Dennis, Maintenance Engineer for the California Highway Department. He estimates the normal capacity of a highway as follows:



2-lane	700 vehicles per hour			
3-lane	2000	"	"	"
4-lane	3200	"	"	"

These figures are for normal traffic which permits fast traffic to travel at 40 m.p.h. and provides sufficient passing space for that purpose. A 30 percent reduction from ideal theoretical conditions was made, so that during maximum congestion the figure can be increased by that amount, making the normal capacity of the 2-lane road 1,000 vehicles per hour.

For safety's sake, and to relieve congestion by making it possible to park a disabled car entirely off the pavement, shoulders should be 8 ft. wide. Embankments not protected by guard rails should have side slopes not steeper than 3 to 1 to prevent cars which leave the road from overturning and deep ditches should be far from the pavement. The roadway widths of culverts and bridges should be the width of the pavement plus the width of shoulders.

Below is a section recommended by the Georgia State Highway Board for shoulders and it appears to be very practical as it not only allows cars to park on the side of the pavement but it has the advantage of keeping the vehicle at an even keel.

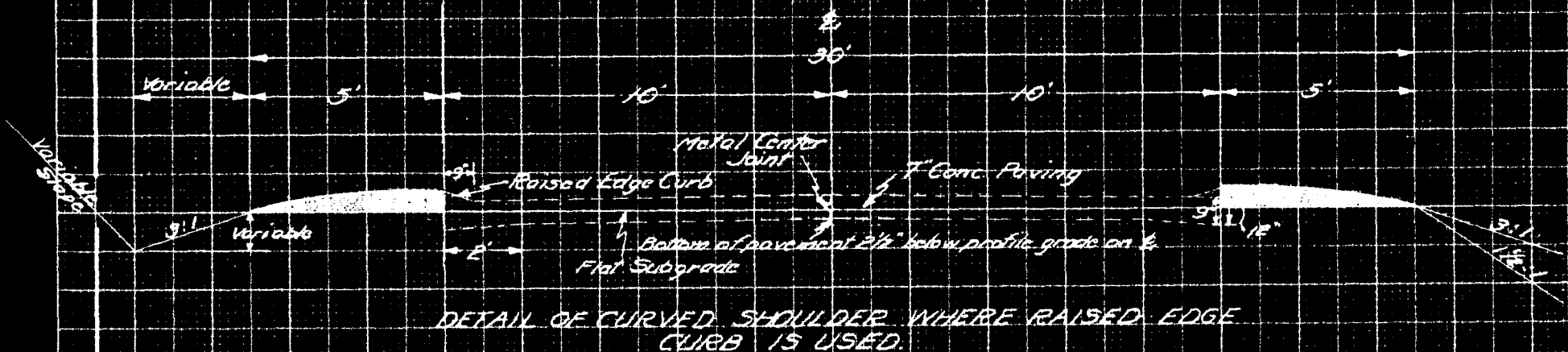
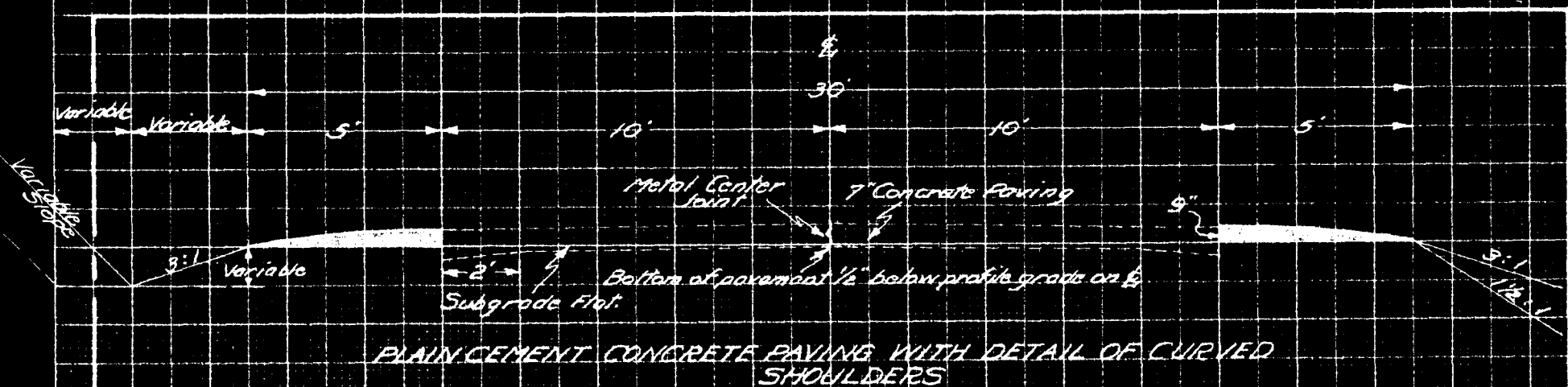


Fig. 2

## C U R V E S.

For both safety and convenience, curves should be made as flat as the character of the country and the interest of property owners will permit. Sharp curves should be avoided, especially at the foot of hills, at bridge approaches and on high fills. Abrupt curves are more dangerous at the end of a long straight road than when they are part of a winding highway. In the former location they should be avoided at any cost.

In mountainous districts sharp curves are often unavoidable. Radii of 50, 60 or 80 ft. have been used without great danger because among the hills, drivers proceed with caution. In flatter country, 500 feet is about the minimum safe radius, while some states seldom use less than 1,000 ft.

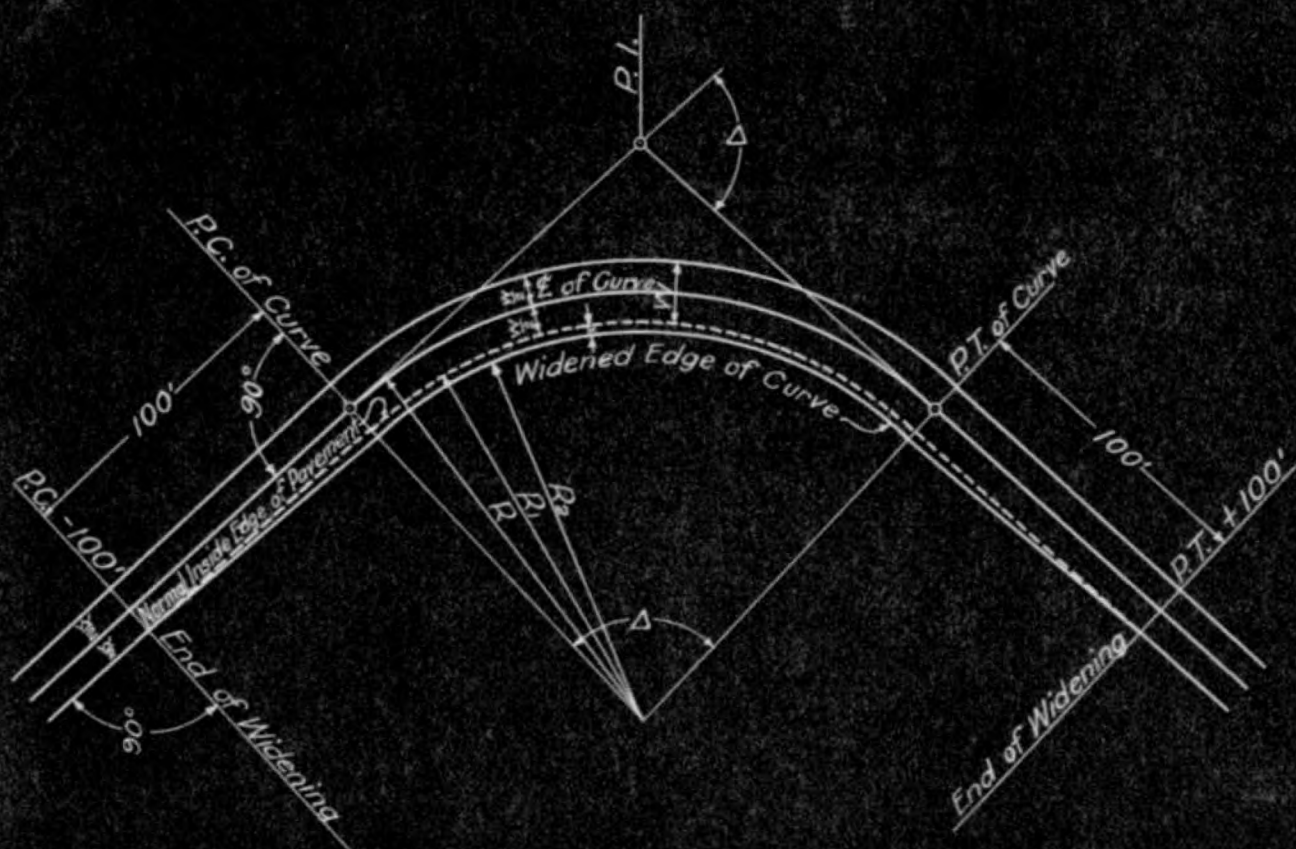
Curves of less than 1,000 ft. radius are now almost universally widened. The State of Georgia widens all those under 955.37 ft. radius. A vehicle on the outside of a curve, with both wheels on the center line, encroaches upon the other half of the road and there is a tendency for drivers to lengthen the turning-radius by cutting across the center line. This, combined with the fact that cars are not under as good control when on curves, has led to widening. The additional width is put on the inside of the curve. A formula suggested by the Bureau of Public Roads for determining widening is:

$$W = 2 \left( R - \sqrt{R^2 - L^2} \right) \div \frac{35}{\sqrt{R}}$$

W = widening in feet

R = the radius of the curve in feet

L = wheel base of vehicle in feet  
(20 ft. suggested)



**TABLE OF WIDENING OF CURVES**

Degree of Curves	Total Widening	Length of Transition Tangent
6°-00' to 7°-30'	2.0'	100'
7°-31' " 15°-00'	2.5'	100'
15°-01' " 22°-00'	3.0'	100'
22°-01' " 35°-00'	3.5'	100'
35°-01' " 47°-30'	4.0'	100'
47°-31' and Over	4.5'	100'

$Y$  = Width of Roadway

$W$  = Width of Pavement

$X$  = Extra Width

$R$  = Radius of Curve at  $\frac{1}{2}$

$R_1$  = Radius of Inside Edge of Normal Pavement

$R_2$  = Radius of Inside Edge of Widened Pavement

**FORMULA**

For obtaining amount of concrete due to widening from P.C. - 100' to P.T. + 100'

$$\text{Area} = \frac{\pi}{360} [100 + \frac{\pi \Delta}{360} (2R - W - X)] = \text{Sq. Yds.}$$

Note: Where concrete paving is widened on curves the center joint strip is to be placed at the center of the paving, and not at the survey center line.

There is considerable variation in the additional width used by the different highway departments but the following is about the average practise:

CURVE RADIUS IN FEET	ADDITIONAL WIDTH IN FEET
100	8 to 10
200	6 to 8
300	4 to 6
500	2 to 4
500 to 1000	2 to 0

Figure # 3 shows the rates of widening used by the State of Georgia:

Pavements on curves are generally tilted toward the inside of the curve to partly counterbalance centrififed force. This tilting is called "superelevation." There are two methods of figuring the necessary super-elevation. In one, the grip of the tires on the road is taken into consideration and the super-elevation necessary to prevent skidding is figured.

This is given by the formula:

Super-elevation in inches per ft.width of pavement =

$$\frac{0.8S^2}{R} - 12 Kf$$

When S = the speed of vehicle in m.p.h.

R = radius of curve

K = percent of weight on rear wheels

f = coefficient of friction between  
tires and pavement when sliding  
normal to motion of vehicle.

Tests have shown that F is about 0.4 for concrete. Assume that K is 0.60 .

This preceeding formula would make curves dangerous when the pavement is wet or covered with ice. If the occupants of the vehicle are to be free from the effect of centrifugal force and curves are to be safe when icy, the tire grip cannot be considered and the formula becomes;

$$\text{Super-elevation in inches per ft. of width} = \frac{0.85^2}{R}$$

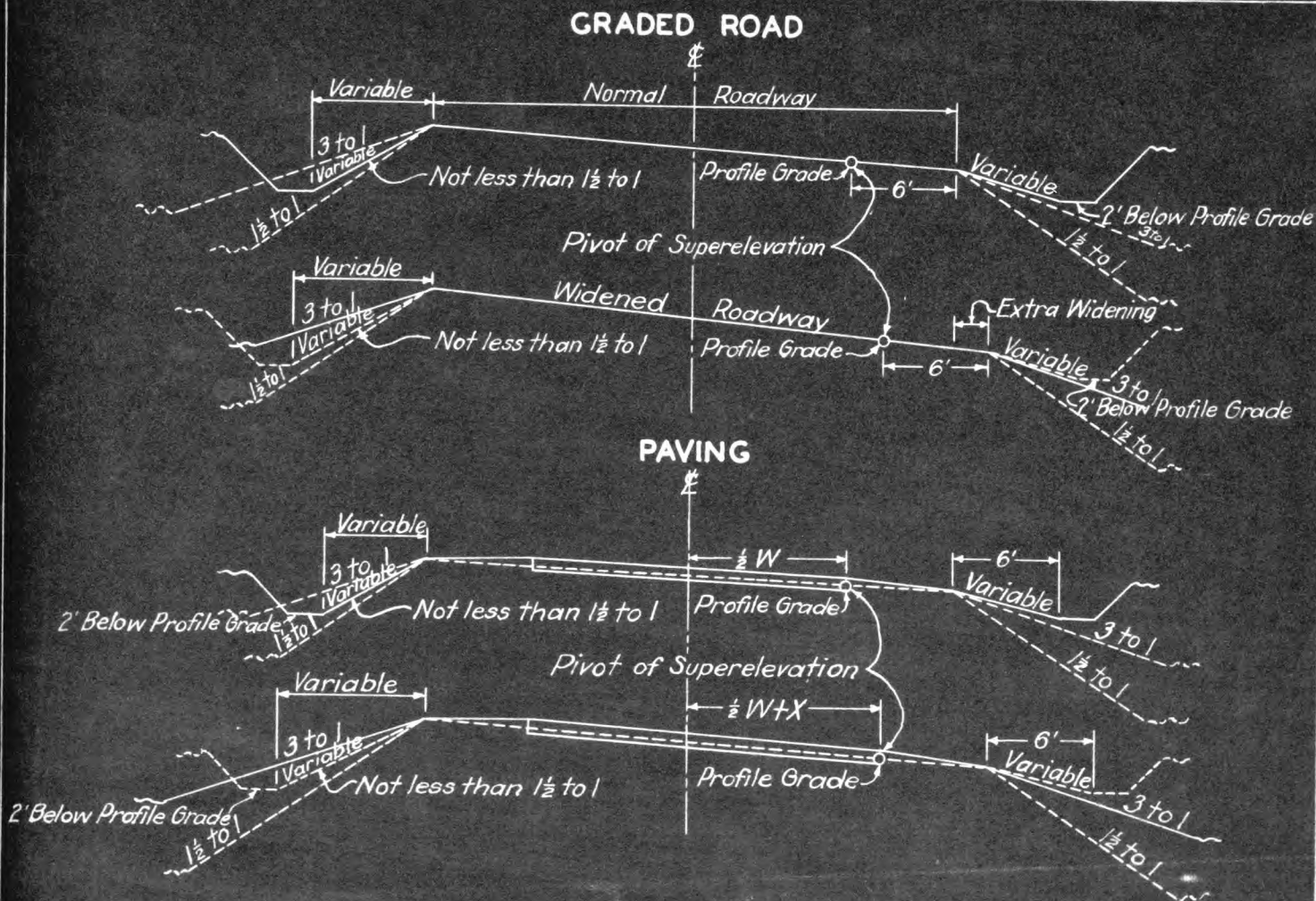
For the common legal speed of 35 m.p.h. this formula gives the following super-elevations:

RADIUS OF CURVE	S.E. IN INCHES PER FOOT OF WIDTH
100	9.8
300	3.3
500	2.0
1000	1.0

As more than one inch per foot will cause slowly moving vehicles to slide toward the low side when the pavement is covered with ice or slime, this is considered the maximum allowable tilt (although in many states this is exceeded with a great degree of efficiency). It is obvious then that all curves of 1,000 ft. radius or less could be given the maximum super-elevation of one inch per foot. Since legal speeds are being raised and it is impossible to tell how fast vehicles will be allowed to go before the roads now being built are discarded, it might be well to use one-inch super-elevation for curves up to 1500 ft. radius (A super-elevation of 26 inches on an 18-ft. slab was used on 30 degree curves in Walker County, Alabama).

Both horizontal and vertical curves should be designed to give sight distances of 500 ft. everywhere.





## METHOD OF SUPERELEVATION AND WIDENING ROADWAY AND PAVEMENT

The position of the pavement with reference to the subgrade to remain the same as on a normal tangent. With the exception of pavements which are to be finished with a machine that can not be adjusted to finish a flat surface, the crown is to be taken out of the pavement in the transition tangent. Full superelevation and widening shall be obtained at the P. C. and maintained to the P. T. The inner edge of concrete paving on all curves to be 9" thick and decreasing to 6" thick at 3' from the edge regardless of the width of the pavement.

TABLE SUPERELEVATION OF CURVES		
Degree of Curves	Rate of Superelevation per Foot of Roadway or Pavement	Length of Transition Tangent
1°-00' to 2°-00'	.03'	100'
2°-01' " 3°-00'	.04'	110'
3°-01' " 4°-00'	.05'	120'
4°-01' " 5°-00'	.06'	130'
5°-01' " 6°-00'	.07'	140'
6°-01' and Over	.08'	150'

Maximum superelevation for bituminous surfaces to be .06' per Ft. of width.

Fig.#4 shows the rates and manner of super-elevation of  
the Georgia State Highway Department.



## GRADE S.

Grade reduction is more important on roads that will carry truck traffic, than on those built primarily for pleasure vehicles. A 9 or 10 percent grade is of less consequence to an automobile than a sharp curve, but trucks and busses are delayed by such grades. In fixing ruling grades it is therefore logical to take into consideration, the sort of traffic the road will carry, the cost of grade reduction and the curves or additional distances which would be necessary if the grade were reduced.

Grades effect gasoline consumption and cause delay. The cost of the additional gasoline and of the additional time required is a measure of the amount which may be spent in grade reduction. In Bulletin 65 of the Iowa Engineering Experiment Station at Ames, data and tentative formulas are given which are useful in determining economical grades. From the data collected during the tests, it appears that when traveling on pavement, the average commercial vehicle used can ascend a continuous 17 percent grade in low gear, 10 percent in second, and 6 percent in high. In high gear, it can ascend grades ranging from 6 to 15 percent on hills ranging from 1000 to 2000 feet in length.

A short section of flatter grade adds safety to a long, steep grade. Maximum grades coincident with maximum curvature are to be avoided and approaches to sharp curves should also have reduced grades.

Most highway departments set 7 percent as the steepest allowable grade on through highways, while other use only 6

percent. Either limit is exceeded where absolutely necessary,  
especially for very short grades.

## THICKNESSES.

Several factors influence the thickness, which slabs must have. The load they are to carry and the strength of the concrete are most important, followed by warping, impact, fatigue, the position on the pavement which the maximum loads will occupy, the use of dowels across joints and the location of joints. Only individual wheel loads are of importance in structural design. The load per inch of tire width is important only when the crushing strength of the material is considered.

In designing highways it is customary to use the maximum legal load as the actual maximum load which the pavement will be called upon to support. In most states, that is 8,000 lbs. per rear wheel, which is about the load of a fully loaded 5-ton truck. Traffic surveys in large cities show that trucks used for city hauling frequently exceed this weight by several tons. For streets leading to depots, building material yards, cement plants, coal yards, sand and gravel plants or other producers of heavy articles it would be well to learn what load trucks from those plants actually carry and make the pavement thick enough to support such loads without damage.

Overloaded trucks come so seldom to the residential street carrying only local traffic, that the allowance for fatigue, explained later, will provide ample thickness to support them. For the ordinary street pavement, then the wheel load may be assumed to be 8,000 lbs; for a business or other street carrying many heavy loads 10,000 lbs; for a street devoted exclusively to heavy hauling, 12,000 lbs.

Tests of six-wheeled trucks indicate that four rear wheels each carrying 8,000 lbs, do not cause any greater stresses than two rear wheels each carrying 8,000 lbs. provided their axles are at least 36 inches apart (from V.L.Gaver's paper before the American Association of State Highway Officials "American Highways").

Dual tires do not solve the problem, because if one strikes an obstruction, the impact of the whole wheel load may come on the edge of the pavement.

Subgrade support is still a subject about which too little is known. It is the weakest point in the design of slabs. Tests are being developed by which different types of soils can be recognized and their characteristics analyzed. The effect of those characteristics on the pavement and the best methods of eliminating undesirable characteristics still remain to be determined. That will require a survey of existing pavements which will probably take several years. In the meantime, it will be necessary to design all pavements for the worst possible condition which assumes that, in the spring, the edges of the slab may receive no support from the water-soaked subgrade and must, therefore, be designed as cantilever beams. This includes edges along a joint at the gutter or along a longitudinal joint between traffic lanes, providing truck wheels can run on these extreme edges.

City subgrades are usually better drained than soil under country roads. Roofs, walks and the pavement itself drain into sewers so that this moisture does not reach the subgrade. Then there are trenches for water sewer and gas mains down which

excess moisture can find its way, so that city subgrades are seldom saturated. City pavements are, however, all too frequently required to bridge places where trenches have settled. When it is remembered that a sub-grade settlement of half an inch is sufficient to eliminate all support of the slab over the settled area, the possibility of no support is better realized. This probably more than outweighs the effect of the better drained soil, making it still necessary to design city pavements without allowing for subgrade support under corners of slabs.

Observation indicates that slabs are warped by differences in temperature between their upper and lower faces. During the day the upper surface is warmed by the sun and expands, curling the edge downward and lifting the center from the subgrade. At night the upper surface cools more rapidly than the lower which is in contact with the warm earth, contracts and curls the edges upward, lifting them clear of the subgrade. This curling action has been found to lift the edges of an 18-foot slab as much as a quarter of an inch above the subgrade, making it necessary to design the slab as a cantilever, regardless of the stability of the subgrade.

Existing data indicate that when the bottom of a pavement slab is in contact with a saturated subgrade and the top is exposed to drying winds, a curling upward of the edges results which is about equivalent to a 3-degree Fahrenheit temperature difference between the lower and upper surfaces.

Tests and actual experience have shown that the edge of a pavement should be thicker than the central portion. This can be best illustrated by imagining a truck wheel in the different positions which it can occupy on a slab. In the center it is

supported by a full circle of concrete, on the edge by a half circle and at a corner by only a quarter of a circle. It seems obvious that if a half or quarter of a circle of concrete is to support a load it must be thicker than the full circle which carries the same load. Both mathematical analysis and tests show that the maximum fiber stress is developed when the load is on the edge of the slab, instead of at a corner, but a corner formula applied to pavements by Clifford Older, checks so well with actual results that it has come into general use. The formula is:

$$D \text{ (the edge thickness)} = \sqrt{\frac{3 W}{S}}$$

When  $W$  = the wheel load in pounds

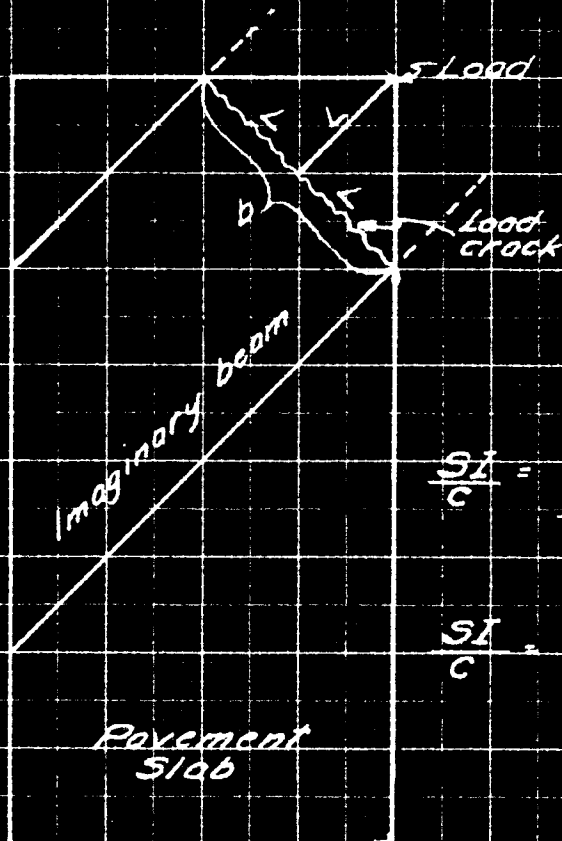
$S$  = the maximum allowable fiber stress in pounds per sq. inch, usually taken as  $1/2$  the modulus of rupture.

For slab thickness along a joint, either at the center line, across the pavement or along a gutter apron, when the two halves of the pavement or the gutter apron and slab are doweled together so that each supports half the load, the formula becomes

$$d = \sqrt{\frac{3 \frac{W}{2}}{S}} \quad \text{or } d = 0.7 D$$

The first formula is used to determine the thickness along edges or joints which are not doweled or mortised to adjacent slabs; the second formula is used to determine the thickness of the interior of all slabs and the edge thickness of all slabs in which the edges are doweled or mortised to adjacent slabs or to the gutter apron. Joints along straight curbs are out of reach

# FORMULA FOR EDGE THICKNESS



$$M = WL = \frac{SI}{C}$$

$$I = \frac{bD^3}{12}$$

$$C = \frac{D}{2}$$

$$b = 2L$$

$$\frac{SI}{C} = \frac{Sbd}{12} = \frac{S2LD^3}{12} = \frac{SLD^3}{3}$$

$$\frac{SI}{C} = \frac{SLD^3}{3} = WL \text{ or } D^3 = \frac{3W}{S}$$

$$D = \sqrt[3]{\frac{3W}{S}}$$

Where:

M = bending moment

I = moment of inertia

S = unit stress in outer fiber  
is modulus of rupture

C = distance from neutral axis to outer fiber

D = depth of beam in inches

W = wheel load in pounds

b = width of beam

L = lever arm = distance from corner  
where load is applied, to crack.

The formula for edge thickness is derived from recognized equations.

Fig. 5

of most loads which usually travel at least two or three feet from the curb or, if they are preparing to stop at the curb, are moving so slowly that impact will be eliminated, so that is not necessary to make the slab thicker at that point. A wheel load 21 inches from the edge has been found to produce a stress along the edge only 47% of that of the same wheel load 9 inches from the edge.

For a water cement ratio of 5-1/2 gallons per sack which is usually the maximum allowed for paving concrete, a 28-day compressive strength of at least 3500 lb. per sq.in. is expected. Such a concrete should have a modulus of rupture of 550 lb. per sq.in. A fair average for all 1-2-3 1/2 concrete 28 days old would be 600 pounds per sq.in. Only half this value (300 lbs. per sq.in) is used in the formula, for reasons which will be explained later.

The load discussed above is the weight of a stationary wheel. A moving load has the effect of a blow on the pavement. This effect is greatly increased if the wheel strikes an obstruction or if tires are worn unevenly and is worst for solid tires. Tests made by United States Bureau of Public Roads indicate that when a worn solid tired wheel traveling at 15 to 20 m.p.h. strikes an obstruction two inches high an impact seven times the static load may be delivered to the pavement. For lower obstructions, the impact was less. For higher speeds, the impact increases almost directly with the speed when the wheel strikes an obstruction, but is reduced when the wheel drops from an elevation onto the pavement.

When trucks are overloaded the impact is not as high a percentage of the total load as for trucks loaded to their rated capacity or less because (1), the unsprung weight which has the



greater effect on impact, does not increase with increasing load and (2), overloaded tires have a greater cushioning effect than those only loaded to their rated capacity.

As obstructions higher than 3/4 inch are infrequent it is generally considered sufficient to allow for impact by using a factor of safety of two.

Several tests have been conducted to determine how great a load concrete would carry before repeated applications would cause failure. In one such test a heavy wheel was run on the ends of cantilever beams, making thousands of circuits at the rate of 40 per minute. In another series of tests beams were clamped at one end and a load applied at the other so that the outer fibres were subjected to alternate tension and compression at the rate of 10 cycles per minutes. Both these tests indicated that loads over 55 percent of the single load which would cause failure would break concrete if they were repeated several thousand times. Subsequent tests indicate that wet beams are fatigued by 45 percent of the single load which will break dry beams. The former tests seemed to show that light loads inter-spersed between the heavy loads lessened the fatigue. As that is the almost invariable condition on pavements, some further investigation of that feature and of the effect of a considerable time interval between minimum loads would be desirable. It is also interesting that in both these tests, the repeated application of a load of less than 50 percent of the modulus of rupture increased the strength of concrete at the stressed section.

Tests made to determine the effect of impact on the fatigue limit indicate that repeated impacts which stress the concrete to about 55 percent of its static modulus of rupture would eventually cause failure.

2

Apparently, then, the possibility of fatigue makes it necessary to reduce the allowable fibre stress to one-half that which will cause failure if applied only once. Provision for usual impact requires about the same reduction in the working fibre stress. But since impact and fatigue do not often operate concurrently and the pavement increases in strength, with age, before the many loads required to produce fatigue could be applied a factor of safety of two is considered sufficient to cover both possibilities and the fibre stress actually used in design is taken as half the expected ultimate modulus of rupture. For the concrete commonly used in pavements, the ultimate modulus of rupture at 28 days, ranges from 500 to 700 lbs. per sq.in. and 300 lbs. is usually used in design.

For a 10,000 lb. wheel load and the above fibre stress the formula gives an edge thickness of 10 inches and an interior thickness of 7 inches. For pavement with separate curbs, with the edge against the curb where it cannot be reached by heavy loads, for pavements with integral curbs, or for slabs whose longitudinal joints are bridged by tie bars, a uniform thickness of seven inches should prove sufficient; that is, for the loads of today. These pavements are to last at least twenty years and if there is a possibility that loads will be increased in that time over the particular pavement in question, it would prove economical to build even thicker slabs. In several metropolitan districts a uniform thickness of 10 inches has been adopted for all pavements carrying heavy truck and bus traffic.

## J O I N T S

Concrete, like most other materials, expands and contracts with changes in moisture content and temperature. The generally accepted coefficient for change in dimension because of change in temperature is 0.0000055 foot per foot of length, per degree Fahrenheit. The highest temperature expected in a concrete pavement is approximately 135°F; the lowest at which it can be laid is 35°F, making a possible maximum temperature difference of 100°F. The change in length from the bone dry to the saturated condition is about 0.0005 foot per foot of length. If a dry slab 100 feet long at a temperature of 35°F. were saturated and raised to 135°F. it would become about one inch longer. As pavements are saturated when built and are usually laid when the temperature is above 50°F., expansion should not exceed one inch per hundred feet.

Unless some provision is made for this expansion, the forces developed may be great enough to raise or even shatter the concrete. That is prevented by installing joints which divide the pavement into separate slabs with a space between for expansion. Some highway departments omit expansion joints, claiming that it is cheaper to repair blow-ups than to install joints, which is true, but there is considerable evidence that the resultant high compressive stresses cause excessive spalling at transverse cracks and probably cause some longitudinal cracking. Whatever the policy concerning expansion joints in roads, they should never be omitted from pavements.

As concrete cools or dries, it contracts an amount approximate equal to that given for expansion. A contracting slab must slide itself over the subgrade. The forces of contraction, opposed by th

# SLIDING FRICTION BETWEEN CONCRETE AND

## - DAMP, FIRM SUBGRADE.

Kind of Base	Move- ment inches	Coeff.	Move- ment inches	Coeff.	Move- ment inches	Coeff.
Level Clay	0.001	0.55	0.01	1.3	0.05	2.07
Uneven Clay	0.001	0.57	0.01	1.29	0.05	2.07
Loom	0.001	0.34	0.01	1.18	0.05	2.07
Level Sand	0.001	0.69	0.01	1.24	0.05	1.38
3/4 inch Gravel	0.001	0.52	0.01	1.10	0.05	1.26
3/4 inch Stone	0.001	0.44	0.01	0.92	0.05	1.09
3 inch Stone	0.001	1.84	0.01	1.78	0.05	2.18

## - THOROUGHLY SATURATED SUBGRADE

Level Clay	0.001	0.14	0.01	0.35	1.5	1.09
Uneven Clay	0.001	0.23	0.01	0.53	1.4	1.06
Loom	0.001	0.17	0.01	0.3	0.75	1.06
Concrete Base*	0.001	2.9+	0.00	2.9+	0.00	2.9+
Oiled Clay	0.001	0.17	0.01	0.47	1.25	1.64
Clay and Cobbles	0.001	0.16	0.01	0.47	1.75	1.45
Sand, oiled	0.001	0.21	0.01	0.32	0.375	0.92
Level Sand	0.001	0.16	0.01	0.32	0.75	1.00
Concrete, oiled*	0.000	2.9+	0.00	2.9+	0.00	2.9+

\* Strength of apparatus exceeded.

friction between the bottom of the slab and the subgrade, set up tensile stresses in the concrete. When these tensile stresses exceed the strength of the concrete, transverse cracks will form. Such cracking is prevented by the installation of transverse joints of either the expansion or contraction type.

The ideal interval between transverse joints is the maximum at which no intermediate cracks will form. This depends upon the strength of the concrete, the weight of the slab, the sliding friction between slab and subgrade and to some extent, upon the amount of reinforcement. If no intermediate cracks are to form, the distance between transverse joints is given by the formula:

$$L = \frac{12 b t S \sqrt{a \frac{E_s}{E_c}}}{\frac{f W b}{2}}$$

Where: L = Distance between joints in feet.

S = The allowable tensile stress in concrete  
in lbs. per sq. in.

a = Area of reinforcing steel.

b = Width between longitudinal joints in feet.

f = Coefficient of subgrade friction.

W = Weight of concrete in lbs. per sq. ft.

t = Thickness of pavement in inches.

E<sub>c</sub> = Modulus of elasticity of concrete.

E<sub>s</sub> = Modulus of elasticity of steel.

Assume  $\frac{E_s}{E_c} = 10$     f = 2    S = 30 (120 with factor of safety of 4. A low value is necessary because stresses begin while concrete is weak.)

Use the above formula for joint spacing in plain concrete slabs, in which case a = 0.

To find the interval at which no WIDE cracks will form, consider the steel taking all the tension. Then:

$$L = \frac{2aS}{f_w b}$$

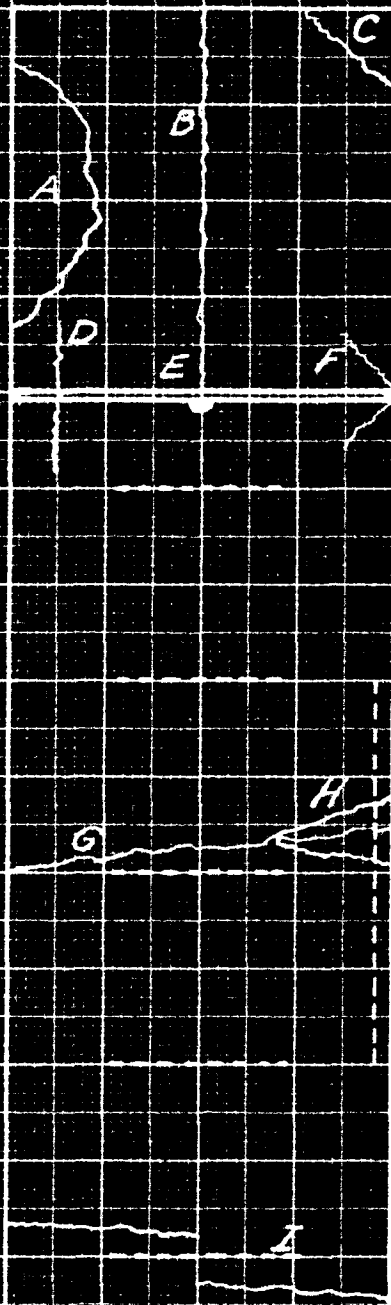
where S is the allowable stress in the steel. In pavements, it is safe to stress steel up to 25,000 lb. per sq.in., and that is the value to use for S. With these assumptions, slabs in a 7 inch pavement 10 feet wide between longitudinal joints should have the following lengths:

THEORETICAL SLAB LENGTHS OF 10 FOOT LANE FOR VARIOUS AMOUNTS OF REINFORCEMENT

LONGITUDINAL REINFORCEMENT	: LONGITUDINAL : REINFORCEMENT : POUNDS : PER : 100 SQ. FT.	: DISTANCE BETWEEN : JOINTS IN FEET	
		: FOR NO : INTERMEDIATE : CRACKING	: FOR NO : WIDE : CRACKING
Plain Concrete	: 0.0	: 28.8	: 28.8
20 1/4-inch square bars	: 42.6	: 29.2	: 25.7
40 1/4-inch square bars	: 85.2	: 29.7	: 51.4
60 1/4-inch square bars	: 127.8	: 30.1	: 77.0

The small increase in slab length for increasing amounts of steel for no intermediate cracking may seem surprising. It is due to the relation of the moduli of elasticity of concrete and steel. When a reinforced concrete slab stretches, the steel carries 10 times the tension carried by the concrete. If we assume that the concrete, being still weak, carries only 30 lbs. per sq.in., then the steel can only carry 300 lbs. per sq.in., so its presence adds very little strength to the slab. Even if the concrete had attained its expected 28-day tensile strength of about 250 lbs. per sq.in.,

## SOME DEFECTS, THEIR CAUSES AND PREVENTION



A is a crack caused by sub-grade settlement. Prevented by uniform subgrade support.  
B is a longitudinal crack caused by curling or by freezing of a subgrade saturated along the edge. If only 3 or 4 feet long, are caused by pressure due to expansion of concrete. Controlled by longitudinal joint.

C is a load crack. Can be controlled by thicker edges.

D is parallel to and 2 or 3 feet from the edge. Caused by failure to extend expansion joint clear to edge.

E is a spall at junction of longitudinal and transverse joints. Caused by failure to extend expansion joint thru longitudinal joint.

F is a crow-foot crack. Cause same as D.

G is a contraction crack. Controlled by a contraction or expansion joint.

H are corner cracks caused by bonded edge bars transferring tension across a transverse crack. Prevented by greasing bar. Note long narrow triangle formed in contrast with isosoles triangle of C.

I is the beginning of a double transverse crack. Contraction of adjoining slabs in opposite directions will, or may, form interior corner breaks. Prevented by transverse joints.

Fig. 7

the steel would only carry 2500 lbs. per sq.in., and the other 22,500 lb. of it's potential strength would be wasted until after the concrete had cracked. Theoretically, these cracks are of microscopic width and would not reduce the beam strength of the pavement nor require maintenance, as the steel holds them together.

There is also pretty conclusive evidence that reinforcement actually causes cracks in concrete slabs when transverse joints are spaced at too wide intervals. In a discussion on tests made by the U. S. Bureau of Public Roads, A.T. Goldbeck says that "More than four 3/4-inch bars in an 18-foot width of pavement seem to cause fine transverse cracks, spaced in some instances only a few feet apart, on slabs longer than those of plain concrete which will not crack." When less than that area of steel is used on long slabs, the frequent, fine cracks do not form but wide cracks occur at intervals a little greater than would be expected in plain concrete. It seems wise, then, to space transverse joints at the same intervals in both plain and reinforced slabs.

While these formulas serve as a basis for the theoretical discussion of slab length and the effect of reinforcement, the one for plain concrete should not be taken too literally, because it is necessary to assume the strength which the concrete has attained when shrinkage stresses begin. Since it is impossible to know what that strength is, it is better to determine the safe length of plain slabs by observation, which indicates that transverse joints should be placed at about 30-foot intervals on average soils.

For the slab lengths in the second column, cracks will form but the steel should hold them so close together that they will require no maintenance and can only be discovered by careful



examination. It should be remembered that the weight per hundred square feet given is for longitudinal steel only; the method of figuring transverse steel will be taken up under "Reinforcement."

As there is a possible expansion of about one inch per hundred lineal feet of slab, provision for this amount should be allowed. There is a growing tendency to make wide expansion joints at longer intervals and install two or three contraction joints between them. Expansion joints are filled with some compressible material plastic enough to be pushed from the joint under pressure but sufficiently stiff to resist melting on the hottest days. If the assumptions used in the analysis are correct, 30 feet would be the best joint interval and condition surveys support this conclusion. On some very bad gumbo and black waxy soils which expand and contract a great deal, 20-foot slabs have been found necessary, while on more stable subgrades very few cracks have formed in reinforced slabs 40-feet long.

Transverse joints should never be staggered unless adjacent slabs are completely separated by longitudinal joints containing expansion material so that independent longitudinal movement is assured.

Longitudinal joints are put in to prevent longitudinal cracking. This cracking may be caused by the warping of the slab or by subgrade heaving or settlement. Experience indicates that all 2-lane pavements should be so divided. For wider streets longitudinal joints should divide the pavement into slabs not more than 15-feet wide. If only one joint is needed, it is located on the center line. If more joints are needed, they should be located where they will receive the least wear from wheels which run along them. Where cars are to be parked, either along the curb or in the center, it is convenient to put any needed longitudinal joints so that they will

bound the parking area. Adjacent slabs need not be of the same width, if more joints are needed than the one down the center line. Combined curb and gutter is coming into disfavor because with it a longitudinal joint is formed where none is needed. Either integral curb, which requires no joint, or separate curb is replacing curb and gutter. No expansion interval need be left in longitudinal joints for width are not great enough to require provision for expansion. It is, however, advisable to fill longitudinal joints with bitumen, after construction, to make them watertight and to prevent wear.

Longitudinal joints between slabs are ordinarily formed by a deformed metal plate whose upper edge comes within half an inch of the surface or by "dummy joints." The two slabs are tied together across the joint with bars which are bonded in both slabs. Some engineers break the bond in one slab, fearing that the fixed bars will act as a hinge and, as the slabs warp, cause spalling along the joint. Such spalling is not common and bonded bars are recommended for longitudinal joints, since with a slipping bar, the slabs can pull apart, destroying the effectiveness of the mortised edge and causing excessive stresses in the concrete. It is desirable that slabs be either firmly tied together, across longitudinal joints, or definitely separated by a thin layer of expansion material. If they are not, the independent longitudinal movement of either slab may cause corner cracking where longitudinal joints intersect transverse cracks or joints.

The number and spacing of the tie bars is easily figured. The load producing tension on them is the weight of the slab between free longitudinal joints multiplied by the subgrade friction. Expressed as a formula this is:

$$aS = LbWf$$

In which the symbols have the same meaning as in the formula for slab length. For a 100-foot section of 7-inch 20-foot pavement with one longitudinal joint and steel stressed to 25,000 pounds per square inch it becomes

$$a = \frac{100 \times 10 \times 87 \times 2}{25,000} = 6.96 \text{ sq.in. of steel.}$$

Tie bars are usually 1/2-inch round, deformed bars which have an area of 0.196 sq.in., so 36 will be required per 100 feet of pavement. If 3/4-inch bars were used only 16 would be required. The bars should be embedded far enough in each slab to develop the necessary bond, which is usually taken as 50 times their diameter. The maximum working stress for bond is commonly taken as 120 lbs. per sq.in. of bar surface.

Dowel pins are put across transverse joints to prevent unequal heaving and to transmit loads from one slab to its neighbor. Dowels should be bonded in one slab but have the bond broken in the other by being coated with paint or heavy grease. There should also be a space left at the greased end into which the bar can slide. Both these precautions must be carefully observed to prevent severe damage at every joint. If the bond is not broken or no space is left at the end of the bar, then the bar will bend under the thrust of the expanded concrete, lift one slab and probably shatter the concrete, or a crack will form at the end of the bars as the slab contracts. The space at the end may be formed by placing on the end of the bar a ball of compressible material, a metal cylinder, or anything else into which the bar can push. It should be about twice as deep as the width of the expansion joint. The material used to break the bond between the dowels and concrete should not be too heavy, for, if the bar fits into the concrete, too loosely, one slab may be carrying maximum stress before the bar transmits

much load to the other slab. A coating of form oil or heavy grease is sufficient.

Dowels are supposed to transmit part of the load across the joint, but, since the amount of its bearing on the concrete cannot be determined, it is impossible to figure what diameter bars should have to keep from crushing the concrete. Dowels must be smooth and are ordinarily 3/4-inch round bars placed in the center of each slab. It has been customary to install dowels at 3-foot intervals but a theoretical analysis indicates that this spacing renders dowels useless, in slabs approximately 7 inches thick, and that they should, instead, be spaced at 2-foot intervals.

T-bars have been suggested for dowels because of their greater bearing on the concrete and greater stiffness for the same weight per foot. Research has found that oil would effectively break the bond between T-bars and concrete.

## R E I N F O R C E M E N T

Opinions differ concerning the necessity for reinforcement. Many state highways are built without reinforcement, though it is used extensively in the northeastern states. Most of the states in the middle west, west and south build plain slabs or use only marginal reinforcement, either in bond with the concrete or as shear bars with bond prevented by painting or oiling the bars. The tendency in recent years seems to have been toward the use of more reinforcement in highway pavements. Steel is more generally used in street pavements than in highways, apparently because city property can afford to pay slightly increased cost to secure freedom from visible cracks.

There is prevalent an erroneous idea that reinforcement is put in concrete pavement to increase its load carrying capacity. That is not the case. To increase the beam strength of a pavement, steel would have to be placed in two layers, one near the top and the other near the bottom, since critical tensile stresses may occur either in the bottom or top of the slab. And it would have to be used in much larger amounts than has ever been considered feasible if it were to add appreciable to the pavements strength. Additional of load-carrying capacity can be secured more cheaply with additional thickness of concrete than with steel.

Tests made at Purdue University indicate the small increase in strength of pavement slabs which can be obtained with steel. Wire mesh weighing 58 lbs. per 100 sq.ft/ was placed 5/8-inch from the tension face of test beams. These beams developed only 13 percent more strength than similar beams not reinforced. In actual construction the steel would be placed 2 inches from the surface, which would greatly reduce its value, so that, instead of a 13 percent increase in strength, less than 10 percent could be expected

Other recent tests indicate that steel increases the strength of wet concrete more than it does dry concrete. That seems to be because moisture expands concrete but does not affect the embedded steel. The steel, being bonded to the concrete, resists the expansion, thus developing tension in the steel and compression in the concrete. This initial compression in the wet concrete must be overcome before tension can exist, so the beam strength is increased accordingly. In these same tests, slabs laid on a dry subgrade required 192 pounds of mesh per 100 sq.ft. to make them have the strength of plain slabs one inch thicker.

In the discussion on "Joints" steel was described as pulling slabs over the subgrade as the concrete contracted. Even in this capacity, steel cannot prevent cracking because the concrete and steel are bonded together. Steel stretches a certain amount under a given load; concrete does likewise and the relative strength of concrete and steel is such that, for equal stretch, steel carries 10 times (approximately) the load per sq.in. that concrete will carry. Then so long as the concrete and steel are bonded together so that they must stretch equally, the steel can only carry 10 times the stress that the concrete will carry. The 28-day tensile strength of concrete is about 1/12 its compressive strength, or approximately 250 lbs. per sq.in. for paving concrete. When the concrete is stressed to its limit, then, the steel can only carry 2500 pounds per sq.in., which is a small part of the stress it could safely carry. Because of the low stress the steel carries, until after the concrete cracks, it is of very little aid in preventing temperature cracks.

Steel does, however, hold together any cracks that form, whether those cracks are due to temperature or to loads, and should therefore prevent settlement and subsequent disintegration under

increased impact. This is steel's only function in a concrete pavement.

When slabs are so long that the stresses developed by contraction are great enough to crack the concrete transversely, all the tension which was carried by the entire slab is thrown on the steel. If the steel is not strong enough it will be broken off at the transverse crack; if it is strong enough to carry all the stress without breaking, then it must stretch much more than when it carried only 10 times the stress the concrete carried. But it is still bonded to the concrete, and, if the steel stretches, the concrete also must stretch; or, in other words, the tensile stress on the concrete is not relieved by the transverse crack and if this stress is great enough it will cause other transverse cracks near the first one. These additional transverse cracks will continue to form until the slab length on one side of the crack is the same as the slab length of unreinforced concrete which will not crack. This explains, theoretically, the conclusions reached from tests made by the U. S. Bureau of Public Roads and quoted in the discussion on joints. It means that transverse joints should always be installed in reinforced concrete pavements and that these joints should not be much farther apart than for plain concrete.

Nor should steel that is bonded to the concrete extend across transverse joints, for the result would be the same for joints as for transverse cracks, tension stresses would be carried across the joint and additional transverse cracks would form.

It is common practice to install bars along the edge of plain concrete slabs to act as shear bars and cause the corners formed by transverse cracks to act together in supporting loads. When transverse joints are spaced at intervals greater than 75 to 100 feet, bond between the edge bars and the concrete must be prevented

or the steel will cause serious corner cracking. The explanation is the same as for the transverse cracking described above. When transverse cracks form, the tensile stresses are carried across the crack by the edge bar and transferred to the concrete on each corner. Since these stresses were great enough to crack the whole slab, they are more than large enough to crack the corners, forming the typical triangular sections shown in the sketch of Figure 7.

These corner cracks may be prevented by stopping the edge bar at transverse joints when joints are not more than 75 ft. apart, or, when joints are farther apart, by painting or greasing the bar so that bond with the concrete is prevented and tension is not transmitted to the concrete by the bar. Edge bar should never be run across expansion joints, because the closing of the joint will bend the bar and shatter the concrete about it.

The amount of reinforcement required depends upon the size of the slab, its length for longitudinal steel and width for transverse steel. The necessary area of reinforcement can be found by solving for "a" in the following formula, which is derived from the formula for slab length for no wide cracks previously given:

$$a = \frac{L_f W}{2S}$$

Where "a" in this case, is the area of steel, in square inches per foot of width or length, running in the direction in which "L" is measured. "L" is the longitudinal distance between free transverse joints when figuring longitudinal steel and the transverse distance between free longitudinal joints when figuring transverse steel. "f" and "W" have the same nomenclature as indicated under the discussion on joints. S, may be given a value of 25,000 pounds per sq.in. as before.



Experience indicates that small bars or mesh are more effective than the same area of larger bars, because they can be more uniformly distributed over the slab. There is, however, greater possibility that the smaller members will be rusted off by the water which seeps into the cracks.

The ratio of transverse to longitudinal steel should be the same as the ratio of width of slab to length of slab, measured between free joints. A free joint is one which is not held together by tie bars. When slabs are held together across joints by tie bars, the tension in the concrete is the same as though the joint did not exist and the width of the slab should be taken as though there were no joint there. Dowels across transverse joints, however, must be built so they will slip in the concrete. Tension is therefore relieved as the joint is "free" to open or close.

Working under the direction of the Highway Research Board, C. A. Hogentogker of the U. S. Bureau of Public Roads made a survey of many miles of concrete pavements to ascertain the value of reinforcement. As digest of this and 18 other reports of reinforcement tests the following can be listed as established facts:

1. Steel reinforcement in concrete pavements delays the appearance of initial cracking.
2. Under certain prevalent conditions reinforcement in concrete specimens increases their efficiency.
3. Steel reinforcement in concrete pavements (after initial cracking has occurred) holds fractured surfaces together, retains smoothness of pavement, resists breakage, and reduces raveling at crack edges.

4. Steel reinforcement in concrete bases prevents escape of sand cushions under brick surfaces and promotes smoothness of bituminous tops.

5. Small members closely spaced are more effective than large members spaced farther apart.

6. In long slabs, continuous longitudinal steel in bond increases, the number of transverse and corner cracks.

7. Bonded steel across expansion joints causes serious fracturing of the pavement.

## C U R B S .

There are three types of curb: separate, integral and combined curb and gutter. The combined type is popular for edging along bituminous surfaces because it protects them from damage by moisture and dirt. It is, however, falling into disfavor for concrete pavements because it makes a longitudinal joint when none is needed and where the joint will be subjected to the wear of wheels running along the edge of the pavement. Separate curb, for business districts, and integral curb with a very flat face, for residential sections, are fast supplanting the combined curb and gutter. Those who still prefer the combined type do so because it is easy to work from the gutter apron in striking off and finishing the pavement. It has, however, one distinct advantage. While a grade of about 0.3 percent is needed to make the other types drain, only 0.1 percent is needed for combined curb and gutter.

Curbs have several uses. When built as an edging for composite pavements they confine the pavement and keep its edges from spreading out. They also serve as a bugger to restrict traffic to the traveled way, to form a wall which makes a neat line between pavement and grass and to hold water on the pavement where it can do no damage. Concrete slabs need not be confined, so curbs along them need only fill the other requirements.

Separate curb usually is designed to protect of few inches below the pavement to act as a foundation in resisting the side thrust of the pavement and of the earth behind it. A design for the depth of the curb would assume that it might revolve around the corner of the slab, or of the base in the case of

flexible surfaces. Then the distance below this point should slightly exceed the distance above, so that the pressure behind the exposed face of the curb would never make the curb overturn, or even push it from its vertical position. Curbs are ordinarily made from 18 to 24 inches deep, 5 to 8 inches wide. They should be divided into entirely separate blocks 6 or 8 feet long by joints clear through the curb. A one-inch expansion joint is needed at the end of all returns and at not more than 50 foot intervals between intersections. A joint in the curb should come opposite a joint in the pavement. The amount of curb above the pavement, or curb exposure, depends upon the quantity of water the gutter will have to carry and is usually made at least 5 inches, which is the amount needed to keep cars from encroaching upon the parkway. The face of separate curbs is often slopes above the gutter line. As drivers hesitate to stop with wheels against the curb, because of the difficulty of turning sufficiently to get out, any curve given the face adds appreciably to the effective width of the street. A 2-inch flat top and a curved face taking up the other four inches of a 6-inch curb is recommended. At intersections or where heavy vehicles may back against curbs, a curb protection bar, cast into the concrete is frequently used. With a face curved or battered so that wheels strike the face instead of the top edge, no protection bar is required and they are not recommended in any case because they all too frequently pull loose and damage several feet of curb. Protection bar should not extend across any kind of joint.

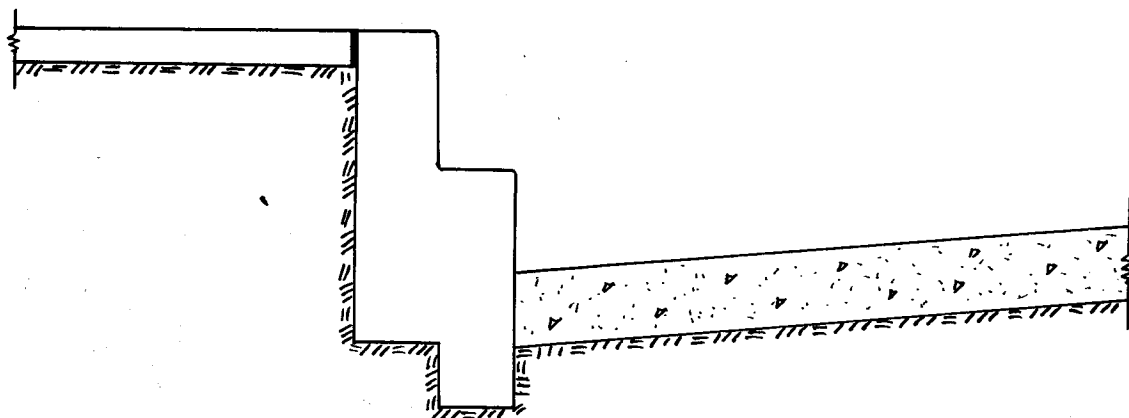
Separate curb is frequently built after the pavement is completed. That makes it possible to haul materials over the pavement and aids construction of the slab because it is easier to finish the concrete with a form at the side than with a high curb. It is a good idea to tie curb and slab together with short, hooked bars to prevent any opening of the joint between them. Two bars in each section are sufficient. When that is done, it is essential that joints in the curb correspond with those in the pavement. It is also possible to set precast straight curb which is sometimes economical because it can be cast during the winter months.

The separate blocks of precast curb are usually doweled together to hold them in line and grade. Similar dowels or a continuous bar, may be used in ordinary curb for the same purpose. The latter must not be bonded with the concrete and the former must slip in one block and have an expansion cavity into which the bar can push.

It has become common practice to put a tile drain below and a little to one side of the bottom of the curb. The trench under the curb is then filled with cinders or gravel. The theory is that the curb and tile will intercept any water which might otherwise seep under the pavement. This is only advisable in soils which contain free water. No tile need be put under a curb on ordinary soils. Where there is no tile, there should be no cinder-filled trench which, without drainage, would form a water reservoir.

Double or "Step" curbs are used in some cities instead of one very high curb. They make it possible to have a high curb on one side of side-hill streets without making the curb an impassable wall and are frequently used where it would otherwise

be necessary to have a warped crown. At intersections both curbs are widened to form steps but in other places are commonly 6-inches wide. The rear or higher curb, is the regular curb, is continuous and has a constant exposure; the inner curb has a variable exposure and disappears entirely when its exposure runs out to zero.



### *STEP CURB FOR HILLSIDE STREETS*

Integral curb is built as a monolithic portion of the concrete slab or base. It acts as a thickened edge to increase the strength of the pavement besides performing admirably the other services assigned to curbs. It is also desirable because no joint is needed along the curb or gutter. Joints through integral curb are limited to the expansion joints which extend through it from the pavement. These should have twice the expansion space allowed for the slab. A few engineers have divided the curb portion into 6 or 8-foot blocks by using division plates, the same as for curb and gutter work, but this is not necessary and detracts from, rather than adds to, the appearance of the street.

41

A rather low curb with a very flat face is becoming popular for integral curb work. A height of 4 to 6 inches with a base thickness of 8 to 12 inches and a face in the shape of a reversed curve extending from the back edge to the gutter line is most used. Such a curb requires no face form, can be built from concrete dropped from the mixer bucket instead of being carried back in shovels, looks well, and requires no opening for driveways. Cars parked along it can stop with their wheels flush with it, or even on top of it, adding appreciably to the width of the street. And to avoid an accident a car could be driven over such a curb and onto the grassed parkway. It does not, however, form a very good buffer to protect pedestrians on the sidewalk from cars which are out of control or carelessly driven.

Integral curb is the only curb built in sections long enough to make reinforcement feasible. A half inch bar placed near the bottom and another two inches from the top would strengthen the curb and help to keep closed any cracks which form, but such bars are seldom used.

The raised edge curb used on highways is not monolithic with the pavement but appears so. It is primarily for the purpose of carrying water along the pavement to a suitable place where it is taken from the pavement by spillways, which are of different designs, depending on the placement of the spillway. They are concrete and if on high fills, corrugated metal pipe is used to carry the water down the slope. This curb is usually placed only on steep grades and insides of super-elevated curves. The curb is placed after the pavement and is generally 3 inches high and 9 inches wide. This curb is shown in Figure 2.

Combined curb and gutter is frequently used on unpaved streets and for streets with surfaces other than concrete. The gutter apron and curb are cast as a monolith usually before the pavement is built and frequently before even the rough grading has been done for the balance of the slab. Then the gutter is used as a permanent grade from which the elevation for subgrade or slab can be taken.

The gutter apron may be any width, from bare 6 inches used only as a guide for finishing tools to a 10 or 12 foot slab put in to form a parking area and protect other pavements from oil drippings. The curb may be any height, from the conventional five or six inches to the two feet or more used to make a storm water canal out of a street. Regardless of dimensions, curb and gutter should be divided into blocks from 6 to 10 feet long and have a 1/2 inch expansion joint at the end of all returns and at 50 foot intervals between intersections.

The slope of the apron toward the curb should be a part of the regular street crown, figured with the parabolic curve formula instead of some arbitrary assumed amount which may not meet the pavement crown properly.

For pavements with a concrete base the curb and gutter may be made monolithic with the base. As bases are frequently of leaner mixes than would be advisable for the gutter, which must take wear, the gutter can be made to two course construction by putting a richer top on the base mixture. In the absence of a scientifically designed mixture this top can be proportioned 1-2-3, or it may be mortar only, in which case a proportion of 1 cement to 2-1/2 sand would prove acceptable.

Where curb and gutter is used with concrete pavement, it is advisable to tie gutter and slab together with 1/2 inch bars



spaced so that there are 2 ties in each block of gutter. These ties can be used also as curb reinforcement by lending them to the shape of the curb. The length of ties can be figured as are those across longitudinal joints, using twice the weight of curb and gutter as the tension in the bars holding that section. It is then absolutely necessary that a joint in the curb come opposite transverse joints in the pavement or the curb will be cracked by the contraction of the pavement slab.

Separate curbs or combined curb and gutter require mixes containing a little less stone than is used for pavements, so that smooth surfaces can be secured. A 1-2-3 mix using coarse aggregate with a maximum size of 1 or  $1\frac{1}{2}$  inches, is common. In some places the stone is omitted entirely and a 1-2- $1\frac{1}{2}$  mortar is used. With the mortar mix, tamping, spading and finishing are reduced to a minimum so that this type of curb is not as expensive as might be supposed.

Curb around the corners of street intersections should have a radius of not less than 15 feet which is the approximate turning radius of the smaller automobiles. The large type of coaches have a turning radius ranging around 30 feet. Some are a little over. On streets which buses will use, curb return radii should be as near these values as possible, so passenger vehicles can turn corners without obstructing or endangering traffic. This is especially important for narrow streets.

Curb returns look best when the point of tangency with the straight curb is at the property line (extended) See Figure 8. On wide streets with narrow pavements, that is sufficient, but in business districts, where the pavement takes up nearly the whole street width, it is not sufficient. For a 26-foot pavement in a 66-foot right-of-way, this rule will give a curb

radius of 20feet and a center line radius of 33 feet, which is sufficient to allow the largest buses listed to turn without obstructing opposing traffic. For narrower rights-of-way or wider pavements a 20-foot return radius would throw part of the curved curb outside the intersection area, but if the point of tangency with the straight curb is not too far from the sidewalk the appearance is not bad. Wherever possible, still flatter turns should be built. Although these may seem to endanger pedestrians because of the faster turning speed they permit and because cars then approach more from the rear, they are really considered safer, because drivers have less to watch and more choice of path.

Many cities are broadening corners on streets which have been long paved by tearing out the old curb and replacing it with a new one with a longer radius.

## C R O W N

Pavements are sloped from center to gutter so that water will drain from them. The less the slope the safer and more comfortable the pavement. Because concrete can be given a permanently even surface very little slope or crown is required to make concrete pavements drain. A crown of  $1/8$  inch per foot of width from center to gutter is sufficient for country roads but  $3/16$  inch is better for streets. No concrete pavement should be crowned more than  $1/4$  inch per foot, except where the slab is warped to fit between gutters of unequal elevation or to vary curb exposures. In those places half an inch per foot is permissible, but should not be used where it will cause cars, rounding a corner, to slide against the lower curb.

Where gutters are at the same elevation on both sides of the street, the slope toward each gutter is the same and the highpoint of the pavement is midway between gutters. But it sometimes happens that gutters cannot be at the same elevation where the curb elevation is fixed by existing sidewalks and the curb face must not exceed the height a person can step. Then the top of the crown is shifted toward the higher gutter. Within certain limits that can be accomplished with equal slopes, but when one gutter is considerably above the other, the slope from the apex of the crown to the low gutter must be made greater than that to the high gutter. In general, the slopes should be kept as nearly equal as possible without placing the apex of the crown nearer than  $1/8$  the width of the street from the higher gutter. If the longer slope is not made steeper than  $1/2$  inch and the shorter slope not less than  $1/8$  inch per foot, the street

will be safe and will drain properly.

The crown of a pavement may either be two planes or a curve. For the flat slopes used on concrete pavements the circular curve formula and parabolic formula give identical results, and the parabolic curve is much easier to figure.

The simplest way to apply the parabolic equation to pavement crowns is to divide the distance from the apex of the crown to the curb into equal spaces. Then if the total fall to the gutter or edge of pavement is "y" inches, the fall to a point  $1/4$  the distance to the gutter or edge of pavement is  $(1/4)^2 y$  inches, to a point  $1/2$  the distance is  $(1/2)^2 y$  inches and  $3/4$  the distance is  $(3/4)^2 y$  inches.

Rather elaborate rules and formulas for crown on grades may be found in many of the older text books. These are used for road surfaces which would wash if water ran longitudinally down the street, but are a needless refinement for concrete pavements.

## INTERSECTION GRADES.

Street intersection grades are frequently puzzling. No fixed rule for figuring them will apply to all cases but the following method will be found useful:

(1) Draw a sketch of the intersection. For ordinary street widths a scale of one inch equal ten feet will make a drawing which will fit a double page of the field notebook, with space for the necessary lettering.

(2) Connect the curb radius points (G) Figure 6, by straight lines. The elevation of the pavement at A, C and E is the mean of the corresponding gutter grades at D plus the total crown of the pavement. The elevation B should be one or two inches above a straight grade between A and E or C and C.

(3) Locate points on the respective enter lines, either by quartering the curb arc, as at ABC or by measuring given distances on the center lines, as on CBE. The latter method is more easily produced in the field before curb returns have been set.

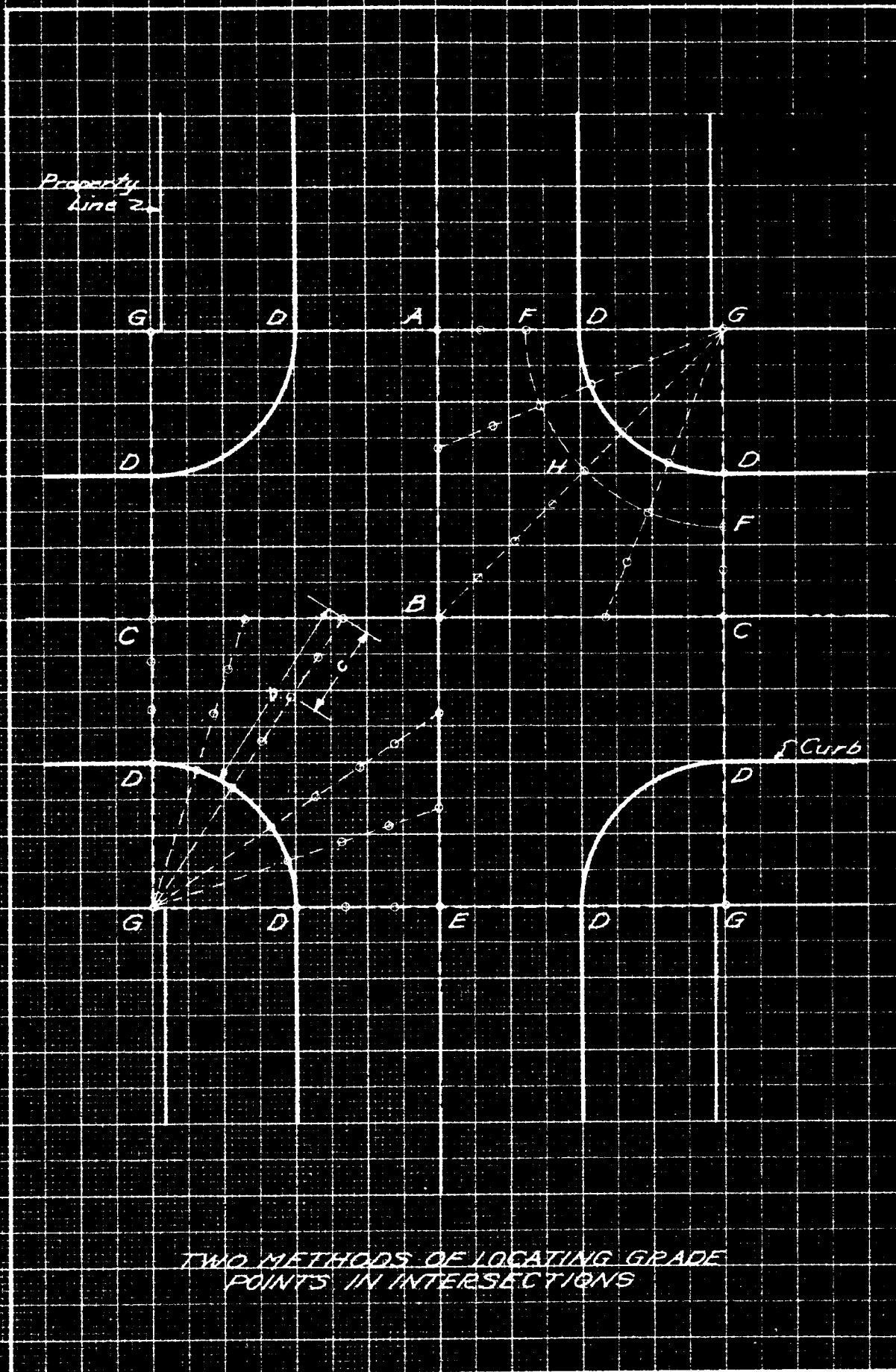
(4) Connect these points on the center line with the curb radius points G by straight lines and measure the distances.

(5) Figure straight grades on the center lines AB, BC and BE and on the gutter around the arcs DD.

(6) Elevation between the points on the gutter line and those on the center line are figured from the parabolic formula:

$$y = \frac{aC^2}{b^2}$$

When a = Difference in elevation between points on center line and corresponding points in the gutter.



b = Distance between points on center line and corresponding points in the gutter.

c = Distance from point on center line to point whose elevation is desired.

y = Fall from point on center line to point in question.

All values are expressed in feet.

Grades obtained in this manner may need to be adjusted to fit special conditions. That is best done by rough-grading the intersection as figured, then altering it till it "looks right." No rules can equal the trained eye in getting a good-looking intersection, but if it is left to the eye alone, poor drainage and bad intersections will be the inevitable result. Always alter the grades in the notebook when they have been changed on the ground so that correct stakes can be set for the concrete work,

When there is a slope from a separate gutter slab toward the center of the street, the intersection of gutter slab and pavement must be rounded off or an unsightly ridge will be formed.

If the apex of the crown has been shifted, between intersections, to compensate for gutters of unequal elevation, the elevation of A, C or E cannot be figured as described in paragraph (2). It can be figured from the grade between intersections. Then this elevation must be combined smoothly with the intersection grades. If F is the apex of the crown, then it can be figured as in paragraph (6) and a uniform grade made from H to F. Elevations between points on FF and the center lines are then figured as described in (6) or as straight grades if the slope is toward the center line.

When the grade between intersections is less than 3 percent it may be carried from center line to center line of intersecting streets without a break, but when it is more it is best to flatten the grade at intersections to 3 percent, by making a break at the property line (extended) and increasing the grade through the block according. If the grade through intersections is more than 3 percent it is nearly impossible to fit sidewalk elevations to curb elevations without excessive slopes on cross-walks.



## D R A I N A G E

Experiments have fairly well proved that capillary moisture cannot be removed from soil. In fact, from tests it has been indicated that untiled subgrade were actually drier than tiled subgrades, winter and summer, spring and fall. That being the case, it is useless to install underground drains for all soils indiscriminately. Drains are needed only where there is free water in the soil-water which seeps through the soil from a hillside or stands in marshy ground. Wherever the soil freezes, such subgrade need to be drained before pavements are placed upon them. That is especially true if the moisture occurs only in spots, for such spots will heave more than the adjacent soil and the unequal heaving will crack the pavement.

This difficulty is almost invariably confined to country roads. In cities the trenches cut for water and gas mains and sewer lines usually provide all the necessary subsurface drainage. There are, however, a few exceptions. Where water from a side hill seeps under the pavement it may so saturate the ground that frost damage will result. Such seepage should be intercepted by a line of drain tile, an open ditch or a French drain before the water reaches the pavement. The trench in which an intercepting tile is laid should be back-filled with cinders or gravel through which water will readily run to the tile.

The pockets in a rock cut sometimes hold water which damages a pavement by expansion when it freezes. Cuts should be made to drain whenever possible, and under-drained pockets should be filled

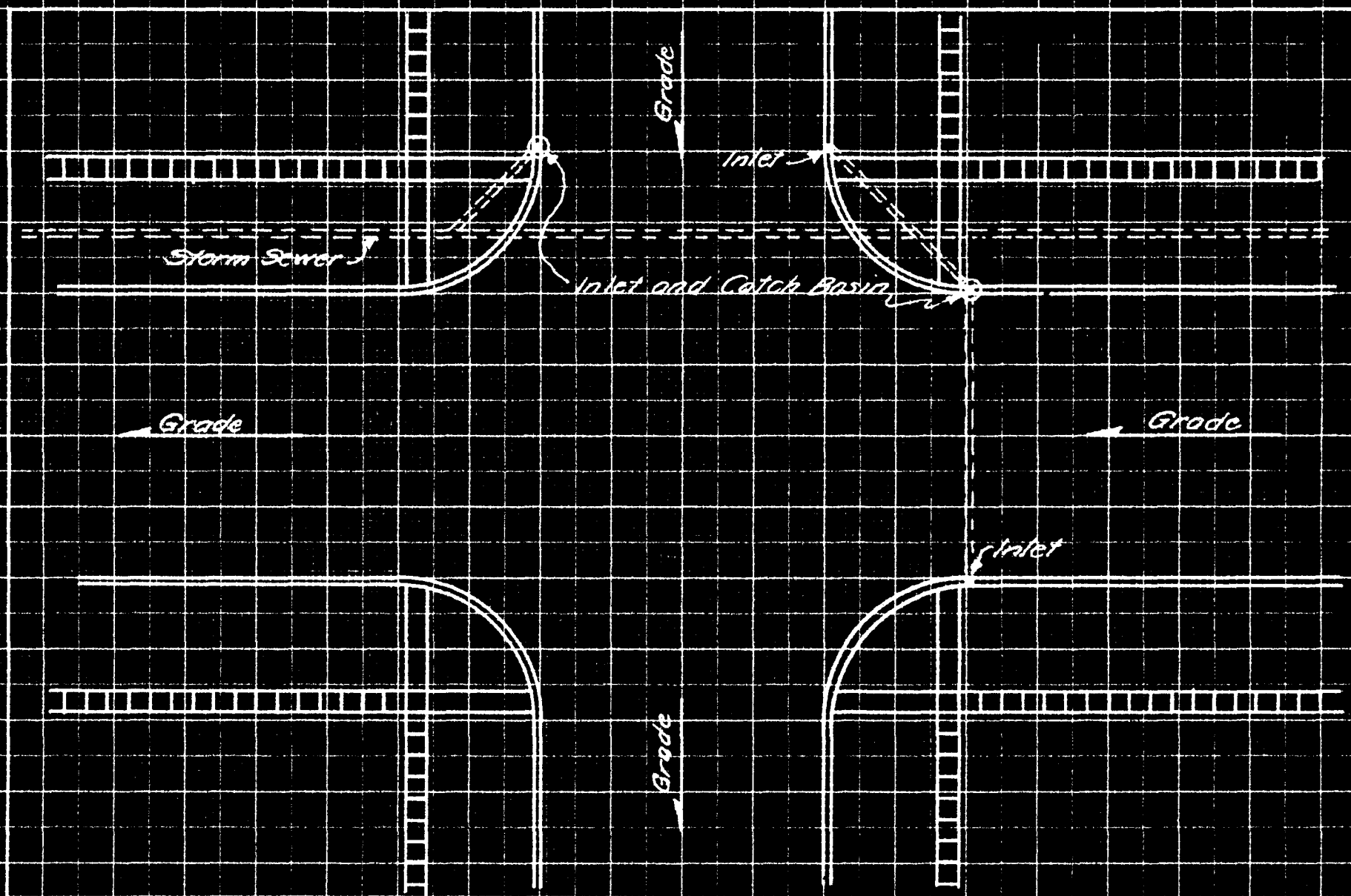


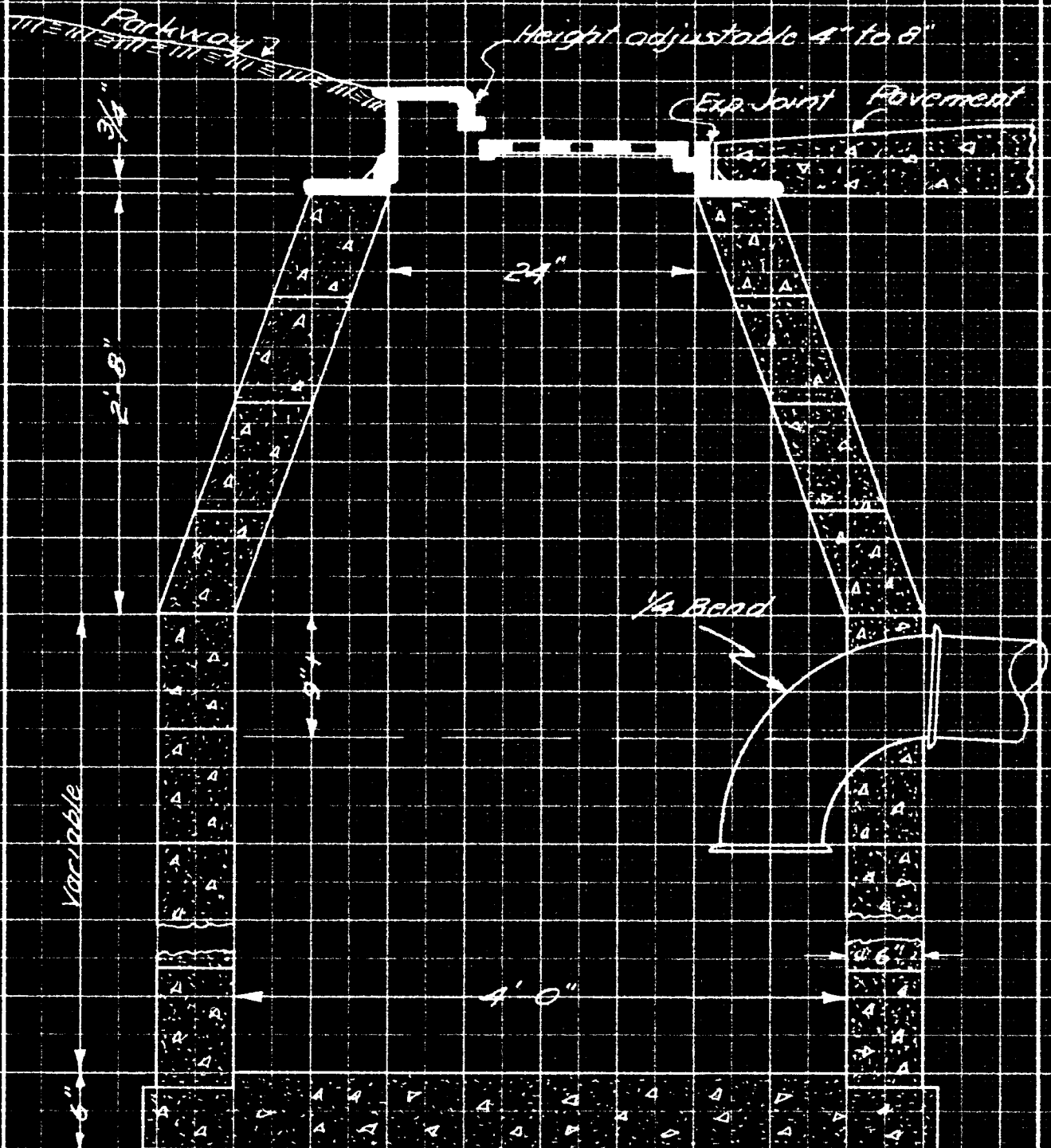
Fig. 9

with sand, cinder, or some other non-absorbent material. An underdrained rock cut has been known to practically destroy the pavement laid through it.

Whenever possible the water falling on pavements should be carried away in storm sewers. The best location for storm sewer inlets is two or three feet outside the crosswalk, so that water will be intercepted before it reaches the area used by pedestrians in crossing the street. That makes 8 inlets necessary at each intersection toward which water runs from four directions, compared with the four inlets which are needed when they are placed at the point of the return curb between the crosswalks. In the former case level crossings are possible, making it unnecessary for pedestrians to slip down from the curb. This advantage is believed to be worth the small extra cost of the inlets, especially since only one additional inlet is necessary when water runs to the intersection from only two directions, which is the usual case. No additional catch basins are needed as the water from two adjacent inlets is led to one basin.

The only satisfactory type of inlet is one which has an opening in the curb face. A grate in the gutter is an additional advantage if the inlet is directly over the catch basin, as the grate can be removed to enter the basin and makes an unsightly cover in the parking strip unnecessary. But in a hard rain, a grate gets plugged with leaves or papers and the water floods nearby yards and basements, causing more damage than the additional cost of a curb opening. Curb openings may be made entirely of concrete, but the cast iron type are usually preferred for the smaller sized openings.

On very flat streets it is sometimes necessary to secure drainage by making the gutter grade steeper than that of the



Concrete Block Catch Basin

Fig. 10

# CATCH BASIN (Reinforced Concrete) (Go State Hwy. Standard)

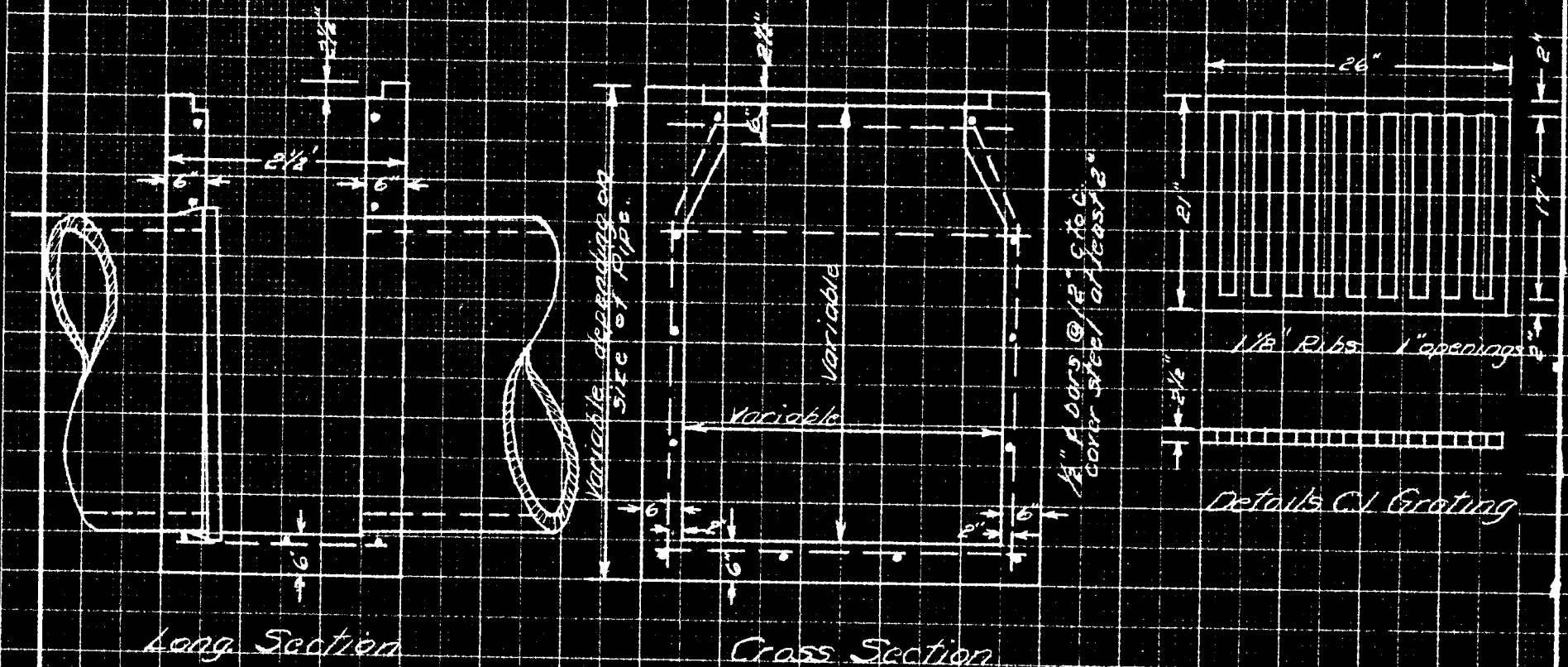


Fig. 10-A

center line. Then the center of the pavement and the top of the curb are carried on a straight grade between intersections. but the curb exposure is made very little at one place and increased as it approaches the catch basin inlet, thus increasing the fall of the gutter. The difference in the grade of center line and gutter produces a warped surface with a very flat crown when the curb exposure is small and a steep crown where it is great. As previously stated, the slope from crown to gutter should not exceed 1/2 inch per foot. If a greater drop from the middle of the street to the gutter is necessary it should be made within a few inches of the curb, when it can be avoided or will only be encountered by slowly moving vehicles.

Warping the slab to secure a variable curb exposure makes special construction methods necessary. These will be taken up under construction.

When there are no storm sewers, surface water must be carried by the gutters to some natural drainage medium. That sometimes requires high curbs, but the chief difficulty is with valley gutters which cut across intersecting pavements. Where valley gutters cannot be avoided they should be laid out carefully with a level. Each side should be a true reversed curve and the bottom should be wide and flat. On appreciable grades the grade of the valley gutter can be flattened, which will make less drop from crown to flow line. The bump at valley gutters is made more severe by any attempt to provide a level crosswalk for pedestrians. While it is sometimes argued that a few valley gutters are desirable because they slow down the speeder, it is the general opinion that anything which takes the driver's attention from the regular job of avoiding cars and pedestrians is an added danger.

Sometimes storm water is carried across an intersection in a conduit. This is a makeshift, but may be used until sewers are built if the conduit is provided with a removable cover, but if it is made of tile or pipe it will clog too easily, especially during freezing weather. Heavy cast iron plates make the best conduit covers.

Wherever it is at all possible, all mains for water, gas, sewers and storm sewers as well as all conduits should be located at some other place than under the pavement. In general, the best place is in the space between the curb and the sidewalk, but any place is better than under the pavement. No more service pipe is required to connect houses with mains on the side of the street than in the center and there are now machines on the market which will push a water or gas pipe through the soil under the pavement in a fraction of the time required to cut through the slab to connect to a main. From the standpoint of both cost and convenience, the parkway is the best place for all service mains.

Before pavements are built, it is best to replace existing iron water service pipes with lead and to run sewer and other house connections from the main to the curb line at vacant lots. This should be done as far in advance of the paving as possible.

## COLORED CONCRETE FOR PAVEMENTS.

Colored pavements are often considered desirable for parks, driveways in private estates and for streets in towns or residential districts which desire "something different". Galveston, Texas, for example, caters to vacationists and pleasure-seekers generally and wants to appear in holiday garb. It has two very pleasing colored concrete streets. Colored walks are much more common and may be found in many parks, in front of theaters and in private grounds.

Recent investigations made by the Research Laboratory of the Portland Cement Association confirm previously held ideas that organic coloring materials are definitely detrimental to the strength of concrete. Most mineral pigments, on the other hand, have no detrimental effect when used in amounts up to 10 percent of the cement (by weight). Since the better grades of pigments are comparatively expensive, it is not probable that more than 10 percent would be desired for any extensive construction work. This is especially true because amounts greater than 10 percent have little additional coloring effect.

For the colors noted the following pigments have been found suitable from the standpoint of permanence of color and effect on the strength of the concrete:

Buff, yellow, red: Iron Oxide Pigments.

Green: Chromium Oxide.

Blue: Ultramarine Blue.

Brown: Iron Oxide or Iron & Manganese Oxide.

Black: Iron Oxide, Manganese Dioxide.

Carbon Black (lamp black), cadmium lithopane and zinc chromate are not suitable for use in concrete. In the tests



mentioned, 2 percent of carbon black reduced the strength of concrete about 15 per cent; 4 percent reduced the strength about 30 percent. Equally dark colors can be secured with iron oxide black but it requires about 5 times more (by weight) than carbon black. In these tests no loss in strength was discovered with iron oxide black up to 50 percent of the cement by weight.

Only the mortar is colored by the pigment. In walks and pavements abrasion will, in time, wear off the thin film of mortar covering the coarse aggregate and thereby change the color of the pavement. This can be avoided by selected coarse aggregate of the same color as the mortar, or of a color which blends with the mortar.

The ratio of color to cement is the most important factor affecting the color of mortar produced by a given pigment. Mixing time is also important; the longer the mixing time the more uniform the distribution of color. For pavements the pigment is commonly put in the mixer skip with the aggregate and the mixing time is lengthened until batches are colored evenly. Experiments indicate that the color is distributed more evenly and rapidly if it is mixed with the cement before it is put in the mixer, but that is expensive.

Color may be used either in the top course of two-course pavements or in the whole depth of a one-course slab.

Attempts to scatter color on the surface and trowel it in have not been entirely satisfactory.

In Galveston, the first colored concrete pavement was two-course, with the color in the top course only. Color was put in as an "extra." The city paid for the color and half the cement handler's time. At that time (1914) the red metallic pigment

cost \$37.50 a ton and 1-1/2 pounds was used per sack of cement. The cost of coloring the pavement was 1-1/2 cents per square yard. The coloring material was scattered over the aggregate in the mixer skip.

On two subsequent jobs one-course pavement was used and the color-extended all the way through. Only 1-1/3 pounds of color per sack of cement was used on this work.

## THE CONSTRUCTION OF CONCRETE PAVEMENT.

### Materials Suitable for Concrete Pavement.

The same qualities which characterize good aggregate for other types of concrete construction are desirable in aggregate for pavement. These are: soundness, cleanness, hardness, toughness, low absorption, non-glassy surfaces and cubical shape. Some of these qualities are even more important for pavements than for any other type of concrete.

Cleanness, for example, is important because any dirt in the aggregate is likely to come to the surface of the slab and form a weak, porous, soft layer called "laitance," which scales off easily, leaving an unsightly rough-riding pavement. It is usually necessary to wash any sand, gravel or screenings before they are used in pavements and crushed stone should be free from dust and dirt.

Soundness is also important, especially in the northern states. Pavements are not often thought of as being subject to severe exposure, like that of a sea wall, but they are. In the early spring and late fall they may be covered with water during the warm hours of the day that is frozen solid at night. Or they may absorb moisture from a wet subgrade. The first essential in a pavement which is to resist such treatment is a dense, waterproof concrete; the second is aggregate which is not damaged by freezing and thawing while it is saturated. Waterproof concrete is secured with sound aggregates completely surrounded by an impervious cement paste. Tests indicate that an impervious paste is secured when the water-cement ratio does not exceed 6 gallons per sack. All doubtful aggregate should be tested for soundness.

Now that even the smaller communities have butcher shops or ice plants with mechanical refrigeration, freezing and thawing tests of aggregate can be made easily, or freezing can be simulated with the sodium sulphate test.

Unsound coarse aggregate has been the cause of both partial and complete pavement failures, indicating that the subject deserves more consideration than it is usually given.

Flat pieces are particularly objectionable for pavements because, when they lie near the surface of the slab, heavy loads may break them out, leaving shallow cavities in the concrete.

Sizes graded from coarse to fine in such a way that there is a minimum of space between particles is important because well-graded aggregate aids in getting dense, waterproof concrete. And it is important from the standpoint of economy, for it takes less cement to get a dense, strong concrete with well graded aggregate than with one containing many voids.

There is a growing tendency to specify a maximum size of 1-1/2 inches for coarse aggregate, because it makes concrete which is easily to place and finish. Well-graded stone running as coarse as 3 inches is used successfully for concrete pavements.

Toughness and hardness are qualities particularly desirable in aggregate for concrete which will be subjected to wear. Wear resistance is determined by tests for abrasion, of which there are two, one for cubical fragments like crushed rock and one for rounded particles like pebbles. The different tests are necessary because the sharp edges of the cubical rock break off quickly in the test and are responsible for much faster abrasion, while the wear on rounded particles was found so slight that a more severe test had to be devised.

It is customary to specify that rock show no more than 7 percent wear in the test for abrasion of rock and that gravel wear no more than 15 percent in the test for abrasion of gravel. Tests made by the U. S. Bureau of Public Roads, however, in which angular particles were subjected to the rock test and then, after the corners were all worn off, to the gravel tests, indicate that coarse aggregate of the same material will wear in the gravel test only 85 percent of what it would in the stone test. That means that specifications which allow 7 percent in the stone test should allow only 6 percent wear for gravel in the gravel test, if the gravel and stone are to have equal resistance to wear. Such a requirement is impracticable however, because one soft piece in the gravel sample might cause the rejection of otherwise satisfactory material and because few gravel deposits could pass such a requirement.

There has been much criticism of the test for abrasion, because many engineers do not believe that it is an accurate measure of quality for concrete aggregate. But it is one of the best and is quite generally specified.

Where there is much steel-tired or tire-chain traffic, rock having a wear of more than 7 percent is not recommended for use in concrete pavement. Rock having a percent of wear of as much as 10 has been used in such locations, however, and the pavements have carried traffic for many years without wearing out or becoming uneven or unsightly. In fact, the mortar and stone seem to wear equally, leaving the surface smooth-riding in spite of a slight reduction in thickness of the slab. Where there is deep snow, so that vehicles travel in ruts and must use tire chains constantly, a hard, wear-resisting rock is essential. Where there is no snow or ice, and consequently no tire chains, softer coarse

aggregate can be used with entire satisfaction, for there is no indication that rubber tires alone wear concrete appreciably.

Regardless of the strengths attained, mixed for pavements should not be leaner than those secured with a water of 6 gallons per sack if the concrete is laid where freezing is common. Particular attention should be paid to the soundness of both coarse and fine aggregate. If either contains appreciable quantities of shale or chert, or if the stone is laminated, with layers of softer material between the laminations, it is not fit for concrete aggregate.

Sands which pass the American Concrete Institute specifications for concrete aggregate are suitable for concrete pavement. Other sand may frequently be used by properly proportioning the mix to give the strength of concrete desired.

The U. S. Bureau of Public Roads made some tests to determine the amount that different aggregates and concrete mixtures would wear when subjected to truck traffic. They built circular track containing 62 different sections of concrete each 4 feet wide and about 10 feet long. There were sections containing crushed stone, slag, pebbles and different kinds of fine aggregate. First two pairs of solid tired truck wheels each weighing 3,000 pounds, or 600 pounds per inch width of tire, made 75,000 trips over a patch 6 inches wide. The front wheel of each pair was then equipped with thre chains and 25,000 additional trips were made. Some of the conclusions from the test follow:

"That rubber-tired traffic alone does not appreciably abrade the surface of a concrete pavement.

"That the rate of wear of concrete is, in general, not affected by the coarse aggregate, provided the coarse aggregate is equal or superior to the mortar in resistance to wear.

6

"That gravel concrete, in general, is at least as satisfactory from the standpoint of wear as stone concrete.

"That gravels consisting essentially of siliceous materials are superior as regards both the amount and uniformity of wear to those containing preponderance of calcareous fragments.

"That gravels consisting of rounded particles are as satisfactory from the standpoint of wear as those consisting either wholly or in part of angular or crushed fragments.

"That the modified abrasion test for gravel in its present form is not an indication of the wear-resisting properties of coarse aggregate. It is suggested that, if the severe impact action of the steel balls were decreased, much more indicative results would be secured.

"That small amounts of shale occurring in the coarse aggregate will cause both excessive and uneven wear.

"That blast furnace slag should prove satisfactory for use in concrete pavements, provided the proportion of light, porous slag is so controlled that the weight per cubic foot will be at least 70 pounds.

"That the presence of large amounts of light, porous fragments in blast furnace slag will cause excessive wear.

"That somewhat better results are secured by the use of the smaller sizes of slag.

"That the copper and lead smelter slags used in these test would make satisfactory aggregates for concrete road construction from the standpoint of wear.

"That slag or stone screenings are, in general, unsatisfactory substitutes for sand as fine aggregates in concrete roads.

"That coarse sands, other things being equal, show greater resistance to wear than fine sands.

"That, so far as resistance to wear is concerned, increasing the cement content beyond a cement sand ratio of 1-2 has no material effect. Leaner mixes, on the other hand, show marked increases in wear.

"That unusual precautions should be taken in using mine chats or other similar harsh-working materials, so as to increase workability to a maximum and thus make possible a smoother surface finish.

"That an excessively dry or an excessively wet mix will wear more than concrete of medium consistency."

The rubber-tired, wheels, without the skid chains, wore the sections made with the softest stone barely enough to make a distinguishable path on the concrete. Since the tests were made, the general acceptance of balloon tires on automobiles and the greater use of pneumatic tires on trucks has largely eliminated the use of tire chains.



## AGGREGATE STORAGE

Modern specifications prohibit the storage of aggregate upon the subgrade because it prevents the proper preparation of the subgrade, makes accurate measuring difficult and results in large quantities of earth being shoveled up with the materials. A central proportioning plant, from which proportioned batches are hauled to the mixer, is the preferred method of handling aggregates; or the concrete may be mixed at a central plant and hauled to the subgrade.

At the plant there will usually be storage piles for sand and stone, a cement warehouse and elevated aggregate bins. Whenever possible, materials are lifted to the elevated bins directly from the railroad cars in which they are shipped. The storage piles are only used to assure a continuous supply and to afford an outlet for a temporary excess of material.

The site for a storage pile should be cleaned of all debris and weeds and, if possible, rolled before any aggregate is deposited. Plans are often specified under stored materials, but are seldom actually used because they are not entirely effective. Every precaution should be taken to prevent (1), getting earth mixed with the materials and (2), segregation of materials. A layer of material should always be left at the bottom of the pile, no matter how badly material is needed, until the completion of the job, when it may be carefully picked up by laborers. Stone forks should always be used for this last clean-up of coarse aggregate and no material which shows a visible trace of earth should be allowed to go into the pavement, for it may seriously affect the durability of the

slab in which it is included.

Segregation of sizes of aggregates occurs in storage piles which have been built up as a cone by dropping material in the center. The larger particles roll to the bottom of the cone and the smaller lodge somewhere between the top and bottom, with the smallest at the top. The worst cases of segregation are found in piles built up by conveying machinery which discharges in one spot only. If, in addition, material is removed, by a loader that work around the edge of the pile, the core and top of the pile may become almost entirely fine material and the base all large rock. A sieve analysis from such a stock pile 20 feet high gave the following results.

SIEVE SIZE	P E R C E N T P A S S I N G		
	SAMPLE TAKEN FROM		
	Inches	Center of Pile	3/4ths of Distance to Outer Edge of Pile
2-1/2	100	100	100
2	94	84	30
1	56	30	0
1-1/4	17	1	0

(From records of resident engineer, Jefferson County, Georgia, 1926, belt conveyor unloader and bucket elevator loader).

The segregation in piles of dry sand is also important but is not so noticeable because of the smallness of the particles.

It is nearly impossible to make good concrete with segregated materials. When the coarse rock is going into the mixer the concrete is harsh; when the center of a segregated pile is being used there is too much fine material. The result is porous concrete in the first case and weak, scaly concrete in the second. Segregation can be nearly all prevented by building piles in layers. Decide in the beginning how large the storage pile will be, then deposit material over this whole area and add to the pile by putting on additional layers 3 or 4 feet thick. This is easy enough when materials are handled by cranes or derricks but requires a special distributing chute for belt or bucket conveyors. Segregated materials can be partly remixed by dropping first a bucket of fine, then a bucket of coarse into the bin.

Some contractors prefer to deposit materials at intersections and haul proportioned batches or mixed concrete from there. Often that makes a better foundation for the pile than can be found at a railroad siding. Otherwise the same precautions should be observed.

## CENTRAL PROPORTIONING PLANTS.

The nucleus of the central proportioning plant is a bin from which materials can run by gravity into measuring boxes and then be dumped into trucks or industrial railway cars for transportation to the mixer. The bins may be elevated or a tunnel may be built upon which the aggregate is piled. Measurement may be by weight, by loose volume or by inundated volume.

Measurement of loose aggregate by volume has been the almost universal method, but it is so inherently in-accurate that it is now being supplanted by other methods. It's in-accuracy is due to the change in volume of sand with changing moisture content. A damp, loose sand may occupy 30 percent greater volume than when dry and rodded. If this change in volume were constant, it could be corrected easily. As it varies with the amount of moisture and the grading of the sand, the only way it can be determined is by frequent test.

The most convenient field method of determining bulking is by unundation. Fill a watertight measure with the sand to be tested, dropping the sand into the measure with about the same force with which it flows into the measuring hopper. Pour the measured sand into another container, fill the measure with water and pour the sand slowly into the water. The original volume, divided by the volume after inundation, will give a factor by which the volume in the specifications may be multiplied to get the volume of loose, damp sand which is to be measured. This factor, minus one, times 100 will be the percent of bulking.

This test measures the bulking due to moisture and also due to the difference between loose and rodded (or tamped) measure. The difference between dry loose volume and dry rodded volume is from 8 to 10 percent.

To avoid this error of measurement the testing laboratory of the Iowa Highway Commission developed a method of batching by weight which has proved highly satisfactory. The weight of sand or stone required for a batch is determined from the weight per cubic foot of the aggregate. The moisture in the sand is determined and is allowed for in figuring the batch weight. Hoppers hung on the levers of either a dial or beam scale are set beneath the bins and material is run into them until the proper weight is secured. It is easy for the operator to come within 5 pounds of the exact weight and still turn out material as rapidly as he could with volume measurement. The moisture in the sand can either be determined by test or assumed as three percent, an assumption which will ordinarily not make an error of more than 2 pounds of material per sack of cement. The sand and stone may either be weighed separately or, with careful inspection, in the same hopper. Batching by weight also makes the use of bulk cement convenient, as it can be weighed with the aggregate.

Cement should never be expected to flow into a hopper by gravity, for it will choke the chute and stop flowing or will drop down in such a quantity that the required weight is exceeded almost instantly. A screw or belt conveyor which carries the cement to the weighing hopper at a uniform rate is essential. It is also essential that bulk cement be measured by weight, as

volume measurement is uncertain.

Seven states specified the measurement of aggregate by weight for 1927 work, 15 required or permitted it in 1928 and 28 in 1929.

While the errors of volume measurement of sand may run as high as 30 percent, the "inundation method" is more accurate, because it measures exactly what is wanted - the rodded (or tamped) volume with bulking eliminated. The theory of inundation is based on the fact that when sand is submerged in such a way that the entrapped air is driven out it has the same volume as the dry, rodded measurement on which proportions are based. The inundator is a box of water into which sand is dropped. Excess water is spilled out. In addition to delivering the correct volume of sand regardless of the original moisture content the inundator also delivers the same quantity of mixing water for each batch, unless there is a radical change in the voids in the sand.

The chief disadvantage of the inundator for pavement work is the necessity for providing truck bodies or containers which are watertight; otherwise part of the water will drain out on the way to the mixer, making it impossible to get two batches of concrete of the same consistency. It frequently happens, also, that more water is required for inundation than is needed for mixing, especially when the coarse aggregate comes directly from a washing plant. In that case, it is impossible to keep the consistency within the specified limits. These two faults have prevented the general adoption of inundation for measuring the fine aggregate going into pavements. Weight measurement is the preferred method, as its growing popularity indicates.

Nor is inundation suitable for the commercial mixing plant because of the difficulty of changing the volume measured each time a different mix is required.

## S U B G R A D E

The one thing to keep continually in mind is that the subgrade should support the slab UNIFORMLY. No matter how yielding the soil, if it supports the slab evenly, it will not cause cracking. If a very hard soil is left in ridges of compacted earth separated by softer material, cracks are inevitable. Concrete roads traversing swamps, for example, have surprised everyone by the absence of cracking, while similar pavements built over old, compacted, macadam or gravel have been disfigured by a network of cracks before the end of one season. The explanation is simple. The soft, swampy soil supports the slab much as water supports a boat and there is no excessive bending; the hard ridges of macadam interspersed by softer material used to fill in depressions support the slab like the knife edges of a testing machine. Heavy loads cause excessive bending and the slab ultimately cracks over the ridge. Usually the crown of an old macadam or gravel road is greater than is required for concrete, so it is scraped off and used to widen the subgrade, leaving a solid ridge of old material about on the quarter points, a loosened center section and edges made of the newly rolled material which was scraped from the center. The result is a pair of longitudinal cracks over the hard ridges, even though there is a center joint.

The remedy is to loosen the old material until the full width of the subgrade, including that under the gutter, is UNIFORMLY SOFT, then roll it until it is uniformly hard. The principal value of the roller is to smooth out lumps, discover soft places and consolidate embankments as they are being built up. A light roller will do this as well as a heavy one; most



71

engineers prefer one weighing 5 tons or less. A heavy roller compresses some types of soil too much, so that they swell while the concrete is hardening, causing cracking.

The equal, thorough compaction of embankments is of paramount importance. The specification usually require that fills be rolled in six-inch layers - a point so frequently neglected and so poorly executed that thorough saturation is recommended as the only means of preventing settlement. Fills can be saturated with a hose by pushing a long nozzle below the surface to about two-thirds the depth of the fill and allowing water to run until it appears at the surface, other than around the nozzle. This should be repeated at 5 to 10 foot intervals in both directions, depending on the character of the soil. After saturation the fill should be allowed to dry out before the slab is placed. Even thorough saturation is not an infallible prevention for subsequent settlement and whenever possible fills should not be paved until at least a year old. Fills of very heavy clay, gumbo and adobe should not be saturated and a dry sand fill will not be compacted by wetting.

The requirement that wagons or trucks dump in long windrows assures fills that are placed in layers. These ridges are leveled with a tongue or blade scraper and new windrows are located between the lines of the old to promote uniform trampling. Fills built with a dragline excavator seem to settle unevenly. Many engineers will not permit the use of draglines to build fills for pavements.

If adobe is pulverized, fills made with it will prove more stable.

Poorly consolidated trenches are sometimes a cause of cracks. Sometimes earth is carried away through poorly made joints in



Forms Set on Completed Subgrade.

(Note Oil on Forms)



Final Check on Subgrade with Scratch

Tooth Template.

sewers or drains, leaving only a shell of earth near the surface. Such places are often discovered by the hollow sound vehicles make in passing over them; frequently they are not discovered until the whole slab has been undermined and falls into the depression. When such places are discovered during construction the pipe line causing the trouble should be uncovered and the leaking joints filled with mortar.

Pavement construction is almost invariably preceded by the installation of water, sewer and gas service pipes from mains to curb line. These newly made trenches are backfilled by men who are only interested in getting the job done. No inspection has ever been developed which can assure fills so well tamped they will not settle. When tamping is allowed, two energetic tampers should be required for each shoveler. Saturation is the best means of compacting trenches.

It is customary to require that the subgrade be shaped within 1/4 inch of its correct elevation before the slab is placed upon it. Whenever the concrete can be struck off with a template a similar template should be used to check the subgrade. This template rests upon the gutter apron, the curb or upon the side forms. The base on which it rests should be at least two feet long, so that the template will not tip as it is drawn forward. The subgrade template should be set to conform to the cross section of the road. The teeth should be set so that they will just clear the subgrade when it is properly prepared and places where the teeth scratch should be cut down until the teeth will clear. Low places must be filled in and well tamped. In intersections, or wherever warped surfaces make it impossible to use a template, the subgrade can be

checked with a level or with "T" boards. The latter are three sticks of equal length, each having a bar across the top to form a "T". By sighting over two of the "T's" held on the edging at the third "T", the elevation of a point above or below the edging can easily be determined. The "T's" can be used to sight in any point between two known points on the same grade line and are surprisingly accurate.

If the subgrade is dry it will absorb moisture from the concrete, which will cause shrinkage stresses while the concrete is too weak to withstand them. This is prevented by wetting the subgrade until it will not absorb much more moisture. Light sprinkling just ahead of the concrete is of some value, but the wetting is best done the night before the concrete is to be laid.

In a test made by the Bureau of Public Roads, one section of pavement laid on a dry subgrade and not covered by wet burlap developed 279 fine surface cracks; an adjacent section, laid on a wet subgrade and kept covered with wet burlap, did not hair check at all.

Adobe and gumbo soils should only be sprinkled lightly, just before the concrete is laid. If they are sprinkled much they will swell and then settle again as they dry, while if they are left entirely dry they will absorb moisture from the concrete, which may cause them to swell and lift the freshly laid slab, either cracking it or making it wavy. Some subgrade treatment is advisable on the worst of these soils. It may also be advisable to oil adobe shoulders to prevent drying and shrinking which will leave the edge of the slab unsupported.

Finely divided windblown soil, called loess, absorbs water like a sponge. If it is sprinkled it becomes mush and trucks

cannot haul over it; if it is left dry it will take so much water from the concrete that excessive hair checking is inevitable. Some covering which will separate the slab from the soil is the only solution.

Subgrade treatment is only needed on the worst clay, gumbo or adobe soils or on loess. The former are improved by granular material like sand, gravel, crushed rock, slag or cinders. This material may be used as a separate layer between the concrete and the soil or be harrowed into the soil to form a crust. The separate layer may be as thin as 2 inches for moderately bad soils, or as thick as 6 inches for the worst soils. It should be provided with French drains or tile connecting with a storm sewer or the side ditches, else it will become a reservoir in which water will collect, to freeze in winter.

A layer of tar paper seems to be the best means of separating the slab from loess soil, though a layer of sand should be equally effective.

These two subgrade treatments have proved effective. All the other subgrade treatments which have been tried proved ineffective or prohibitively expensive.

## MIXING CONCRETE.

Time is the most important factor in mixing. Concrete of the quality common in pavements is from 20 to 35 percent stronger when mixed two minutes than when mixed only 15 seconds. This is largely due to the increased workability secured with longer mixing and the possible decrease in the quantity of mixing water.

Thorough mixing increases the uniformity of concrete. In tests to determine the effect of mixing time, specimens mixed for only 15 seconds showed an average variation from the average strength of 30 percent, while those made of concrete mixed two minutes varied less than 10 percent. Another advantage of thorough mixing is that it is of great assistance in securing watertight concrete. The speed of rotation of the mixer has little to do with thorough mixing within the commonly accepted limits of from 12 to 20 revolutions per minute. One minute should be the absolute minimum mixing time.

Mortar collecting on the blades of the drum greatly reduces the mixing action and should be cleaned off at once. If mortar hardens on the blades during the regular operation of the mixer, as it sometimes does in very hot weather when accelerating admixtures are used, the blades can be kept clean by depositing the batch in the skip so that the coarse aggregate goes into the drum before the sand and cement. Calcium chloride used as an admixture should be put in with the mixing water, otherwise the highly concentrated solution may cause mortar to harden on the inside of the drum.

Tests made show that overloading a mixer materially reduces the strength of the concrete. They also indicate that the

76  
manufacturer's rating of capacity is accurate and should be used as the maximum permissible amount of concrete the drum will hold. A 21 or 28-E mixer will turn out 21 or 28 cubic feet of mixed concrete satisfactorily.

If there is no reserve tank on the mixers a double hose connection and two lines of hose to the mixer will eliminate the loss of time when changing hose.

Many specifications require that the mixing water all be in the drum ahead of the materials. Mixer manufacturers have found that this is not good practice; it makes a concrete of uneven consistency and one which is not otherwise so well mixed as when water and materials are introduced together. The requirement is obsolete and should be omitted from specifications, especially since few, if any, modern mixers meet it.

## PLACING CONCRETE.

There are a few general precautions to be observed when placing concrete. Workmen should not track dust or mud into it nor should the subgrade be sprinkled in such a way that dust is thrown onto the exposed edge of the slab. Workmen should not be allowed to roam around in the concrete after it has been struck off. Footmarks are usually filled with mortar largely composed of laitance and often show as depressions after a few years' wear.

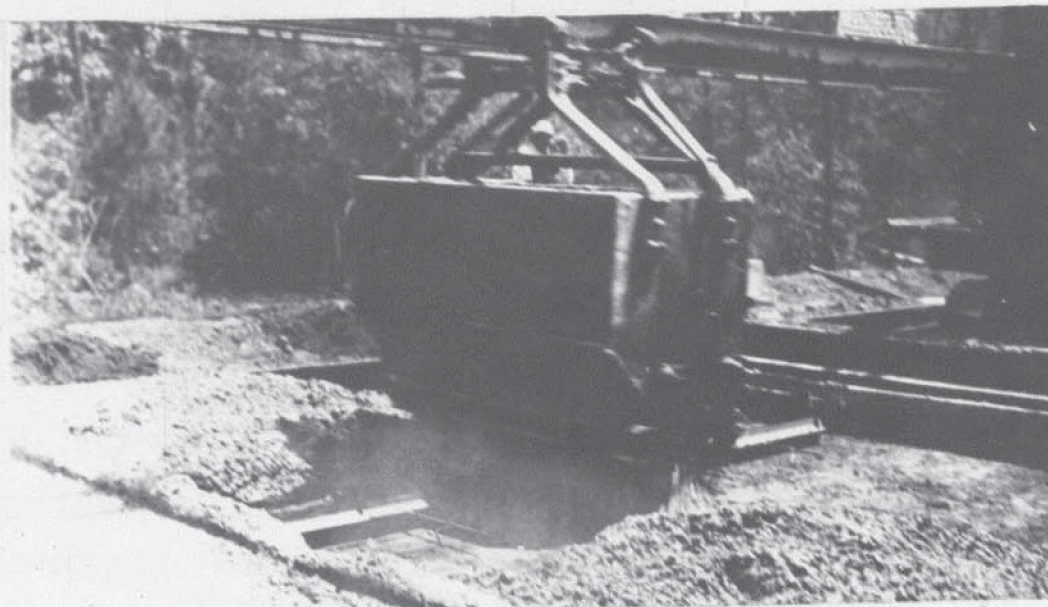
Whenever the mixer is shut down long enough for the concrete to commence hardening, a square butt joint should be made. Otherwise a sloping line of weakness will be left which may push up under the thrust of expansion or crack as the slab contracts. Even when the mixer is stopped for only 10 or 15 minutes the new and old concrete should be thoroughly sliced together with shovels to make sure that no cleavage plane is left.

It is advisable to use concrete a little deficient in coarse material next to joints at noon and night stops. This is especially true of the first batch mixed in the morning, for some of its mortar points the mixer drum and porous concrete is especially objectionable at joints.

A straightened hoe or straight spade with holes cut in it should be worked up and down in the concrete next to the forms, gutter apron or joints to draw mortar to the edge of the slab and assure a face free from honeycombing.

Some engineers require that the slab in intersection be struck off with a template. For intersection with center joints and no valley gutters, that is accomplished by setting forms





Placing the Concrete by Means of Dump Bucket,  
Working Directly From the Mixer. Note  
the Metal Center Joint in Place.



Just in Front of the Finishing Machine.

on the center lines of both streets and along the curb, if there is no gutter apron. A template rests on these forms and strikes of the slab. If there are valley gutters, guide forms can be set on the gutter line and the same template be used in the intersection as in the rest of the block. Considerable shaping of the slab outside the limits of the template will be required, or this method will result in spring-breaking valley gutters.

Valley gutters may be eliminated by carrying surface water across intersections in a covered trough, but that is advisable only where the trough will not be liable to clog with ice. It is nearly impossible to keep such a trough clear in the northern states. The cover should be removable to facilitate cleaning. A heavy metal plate is commonly used for a cover.

Ordinarily intersection grades are defined by stakes carefully set by instrument. No intersection should ever be built without such stakes, unless a template is to be used. Between stakes the concrete is leveled by shovels and floats or wooden lutes. Rakes should not be allowed.

When possible the wings, or that portion of an intersection outside the curb lines of the street on which the mixer is working, should be put in first and far enough in advance so that workmen can walk on them in finishing the rest of the pavement. If the cross-street is also to be paved soon, these wings may be left until the mixer is working on the cross-street. The expansion joints form a convenient line between the sewer and older work.

Gutter grades adjusted to make a variable curb exposure and provide drainage on level streets produce slab surfaces which cannot be struck off with an ordinary template resting

on the curb. Adjustable templates, whose drop from curb to slab is changed as the curb exposure increases, have been tried but have not been very satisfactory because the change in exposure is gradual, rather than periodic.

Crowns ranging from very steep to very flat, used with variable curb exposure to get drainage toward catch basins on flat streets, can be struck off with a curved template whose ends rest on a form at the center line a guide rail near the curb set at the proper elevation for the finished slab. The template should be cut to give the proper crown to the flatest portion of the slab, using the parabolic curve and making the center half of the slab as flat as possible. When this template is used on slabs with a steep slope, the crown will approach that of two flat slabs, meeting at the center line in a ridge. When the gutters are not at the same elevation on opposite sides of the street, slabs can be struck off with the regular curved template used for other work. This automatically shifts the apex of the crown toward the higher gutter, flattens the up-hill slope, steepens the down-hill crown and has been found very satisfactory.

If no template is used, the crown is defined by stakes set at the elevation of the finished slab, either with a level or with "T" boards. Metal stakes with a lug one inch below the top are best. The lug is set at the elevation of the slab and an inch of stake will protrude from the concrete, furnishing an additional check on the grade and making it impossible to leave stakes in the pavement.

Grade stakes should be set about 10 feet apart both ways, but should at least be placed on the center line and quarter points. For straight curb a chalk line may mark the slab

80

elevation next to the curb. The gutter line should be carefully checked with a 10 foot straightedge and, if flat, with a carpenter's level to assure proper drainage. The flow of excess moisture from the concrete may also be watched.

Shovels and long-handled floats are used to place concrete properly where the crown is defined by stakes. A longitudinal float aids materially in getting a smooth-riding surface.

## PLACING REINFORCEMENT.

Cracks in the upper surface of a slab are especially to be avoided. When there is only one layer of reinforcement, it is placed near the surface where it will hold these cracks together. Steel should be placed at sufficient depth to protect it from moisture. That is usually assumed to require a 2-inch covering of concrete. Mesh reinforcement is usually placed in the proper position by first spreading a layer of concrete to within 2 inches of the surface, laying the mesh on this and then completing the slab. If a finishing machine is used, an auxiliary strike-off may be hinged to the regular strike-off template to level the first layer of concrete, otherwise it is usually done with shovels or a hand strike-off. In some places the mesh is supported on a sled made of pipe or timbers, the concrete is placed around and above it and the sled is pulled forward as the mixer moves ahead. This device serves very well, so far as supporting the steel is concerned, but drilled cores indicate that the cavities left when the sled is pulled out do not always fill with concrete. Cases have also occurred where sleds made of "T" bars have caused longitudinal cracking.

Mats formed by tying steel bars together can be supported on metal chairs which are left in the concrete. Edge bars are almost universally supported on metal chairs which may or may not be removed after sufficient concrete is deposited to support the bar.

The practice of laying mesh on the subgrade and pulling it up into the concrete placed over it is not recommended. Cores and trenches under the pavement have shown that much of the



82

steel placed that way never gets off the subgrade. The steel is almost never left in the position specified or intended. Laying the mesh on top of the concrete and attempting to push it down to the required depth is also bad practice.

In business districts or on any streets where it would be a definite hardship to property owners if the street were kept closed, half-at-a-time, construction is advisable. Sometimes it is even best to build one traffic lane at a time and open it to traffic before the other lanes are closed. In such places, high early strength concrete, is worth many times its additional cost.

If the longitudinal joint between slabs is to be made by a deformed plate, this is fastened against the forms in its proper position. The dowels are bent at a 90-degree angle and one end is put in the concrete while the other is laid along the groove in the deformed plate. If no plate is used the end of the dowel intended for the adjacent slab is laid along the form. Encasing that end in a paste-board tube will aid in freeing it from the concrete. In either case, the dowel is bent out straight after the concrete has hardened, just before the other strip is laid. When wood forms are used, the groove for the mortised joint may be made in the first slab laid by nailing a wooden strip to the forms. This strip should be triangular in section and can be made by ripping a 2 by 2 along a diagonal. It should be kept oiled to prevent swelling and to permit easy removal.

It is extremely important that no "fingers" of concrete bridge expansion joints and the end of each joint should be cleaned out with a chisel until the expansion material is fully exposed.

Slabs up to 30 feet wide can easily be laid at one time, eventhough they are separated by longitudinal joints into two or three traffic lanes. It is, however, difficult to obtain a smooth-riding pavement when slabs more than about 20 feet wide are struck-off and finished in one operation, so half-at-a-time construction is growing in popularity.

## J O I N T S .

There is one thing of pavement importance in joint construction - TO HAVE THE JOINT TRULY PERPENDICULAR TO THE SURFACE OF THE PAVEMENT. If it is not perpendicular, the pressure of expansion will cause one slab to slide on the sloping end of the other. Joints should run straight across the pavement if they are to look well and it is important that the filler be continuous from one edge of the slab to the other, for, if even a small wedge of concrete spans the joint, spalling or cracking will probably follow.

Expansion joints are usually made by installing premolded filler just before the concrete is placed. The filler is held upright by a bulkhead staked in position. Metal bulkheads are better than plank because they are thin and easily removed without pushing the filler out of line. A metal bulkhead which is folded over to form an envelope for the top of the filler, to hold it down in spite of the tendency of the concrete to float it, is popular. If the bottom half of this bulkhead is notched so that it has teeth like a saw, the concrete will come in contact with the filler through these notches and hold it in place when the bulkhead is lifted. Another excellent bulkhead is made like a strike-off template but has a double row of spikes set in the bottom. The ends of the template rest on the curb and its bottom edge is at the elevation of the pavement. The filler is inserted between the two rows of spikes which hold it in place while the concrete is placed around it. Then the template is lifted straight up. As only the spikes have been in the concrete only a few small holes are left along



86

the filler. This device must be built so that the mixer bucket will clear it. Such a bulkhead has recently been put on the market. It is made of steel and is so shallow that the mixer bucket will not strike it.

When a plank bulkhead is removed a large space is left on one side of the joint filler. The pressure of the concrete on the other side of the filler will force it out of line toward this unsupported side unless the bulkhead is removed slowly, from one end, and the cavity filled as the bulkhead is lifted. Even with extreme care, it is difficult to get a good joint with a plank bulkhead.

It has been customary for specification to require that the strike-off template move away from joints, but this is almost never done. Pulling the template right up to the joint presses the top of the filler forward and makes a leaning joint. Sometimes it also piles concrete up behind the joint and makes it noticeably high. Since it is difficult to work backward from a joint, in striking-off, some engineers and contractors prefer to use joint material whose width is  $1/4$  inch less than the depth of the pavement. Then the slab is finished right over the joint, as though it were not there, and when all finishing operations have been completed, the concrete over the joint is removed and the edges are rounded. Under no circumstances should concrete be left over the filler, for the pressure of the expanding slab will break out this thin layer and cause spalling to a width of a foot or more.

"Poured joints" are sometimes preferred. When they are used a slightly wedgeshaped bulkhead is left in the slab when the pavement is finished. After the concrete has hardened enough so that it will not flow, the bulkhead is removed.



After The Slot for The Dummy Joint is Cut, Strips of Premolded Filler 2 inches wide are pushed Into it and Finishing is Completed.



Expansion Material Extending From Subgrade to Just Below The Surface of The Pavement Uncovered Immediately After The Final Finishing Operation, Makes Smooth Riding Joints.

84

The joint is completed by first cleaning the crevice with a pointed hook and the filling with hot bitumen. The chief advantage is that the stiff bulkhead is more easily held in the proper position. The joint may be inspected before it is filled and if it is not perpendicular to the surface the installation methods can be changed so that future joints will be right - an inspection which is nearly impossible with the premolded type. There is some danger, however, of cracking the concrete a foot or two from the joint when the bulkhead is lifted, and, if the bulkhead is pulled too late and the edges of slab are disturbed after hardening has progressed too far, the disturbed sections may later break loose from the slab. Some patented, collapsible bulkheads are on the market.

To insure continuous expansion space from edge to edge, the filler should either be in one piece of the proper length or shorter pieces should be fastened securely end to end with clips. Unless it is especially cut, the filler will not fit against deformed plate so tightly that no concrete will bridge the joint. For that reason the center plate should be stopped from 1 to 3 inches from the joint so that the filler can be made continuous across the center joint, or spalling at the intersection of joints will result, as shown in Figure 7.

The metal center plate should not extend across any transverse joints because as the slabs contract, tension across the joint will cause interior corner cracks. Wherever the end of an expansion joint is exposed to view it should be inspected and if any concrete bridges the joint it should be cleaned away with a chisel.

A 1/2 inch expansion joint should be left around all man-hole cover, poles, water cur-off boxes or other structures which protrude through the pavement. Some movement of the slab is certain to take place, and, unless allowance is made for these rigid structures, the pavement will be cracked. A piece of premolded joint filler, held in place with a strand of wire, is the best.

Contraction joints are either the weakened place type or the submerged, deformed plate described for longitudinal joints.

The deformed plate is installed at a depth of a half inch or more beneath the surface and should be continuous from edge to edge. It is essential that a groove be cut in the pavement directly above the plate, for otherwise the expansion of the slab will cause serious spalling along the joint. The groove should go down to the plate and be finished with an edger. It is made by putting on the plate a metal cap which can be removed after the slab is truck-off; or a straightedge may be laid on the surface directly above the plate to serve as a guide for an edger. The straightedge is properly located by feeling for the plate with a small trowel after the other finishing operations are completed.

The dummy joint is a weakened plane made by cutting through the top 2 or 3 inches of the slab. The cutting tool may be the web of a "T" bar 10 or 12 feet long, fastened to a plank for stiffness and provided with plow handles, or it may be a sharp-edged wheel which is run along a straight edge. There are also patented machines which make both longitudinal and

transverse dummy joints by forcing a thin metal strip into the pavement. They ridge on the forms.

Dummy joints have been enthusiastically approved by engineers and contractors except where the coarse aggregate is a harsh-working crushed stone. They are good looking and effective and usually cost less than joints made with the deformed plate. When the slab contracts, the concrete below the slot cracks, but the cracked edges are rough and cling together so that independent heaving is prevented. The slots made by edging above the deformed plate or by the tool which forms the dummy joint are filled with bituminous material before the pavement is opened to traffic.

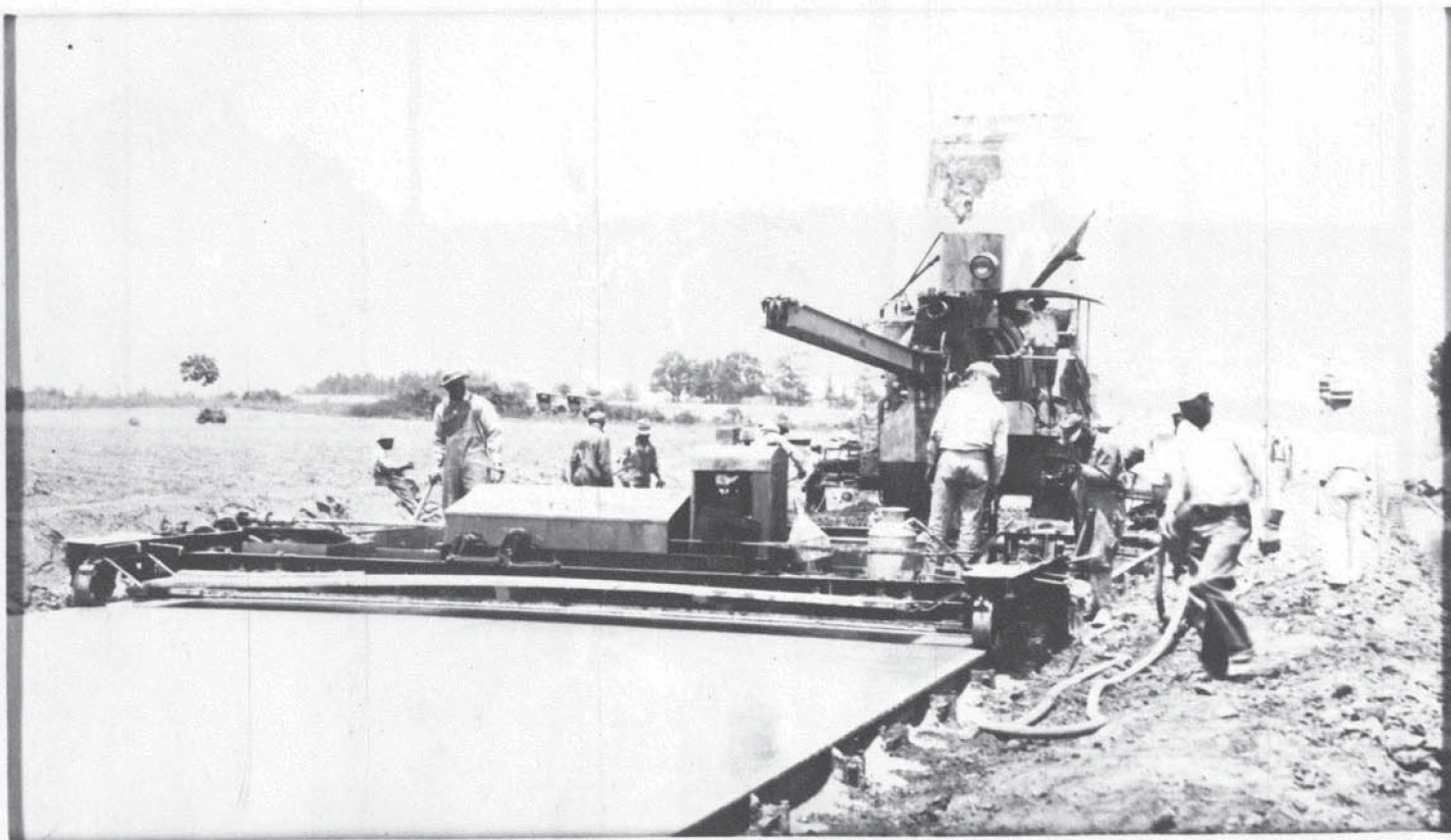


## F I N I S H I N G .

So far as public approval goes, a smooth-riding finish is the most important feature of a pavement. The average motorist knows nothing of the hours spent in testing materials, in design, or in securing the proper quality or quantity of slab; all he is interested in, is: "How does it ride?" Finish also affects the life of the pavement, since a rough surface materially increases impact. A concrete pavement should not vary more than 1/4 inch from a 10-foot straightedge laid parallel to the center line.

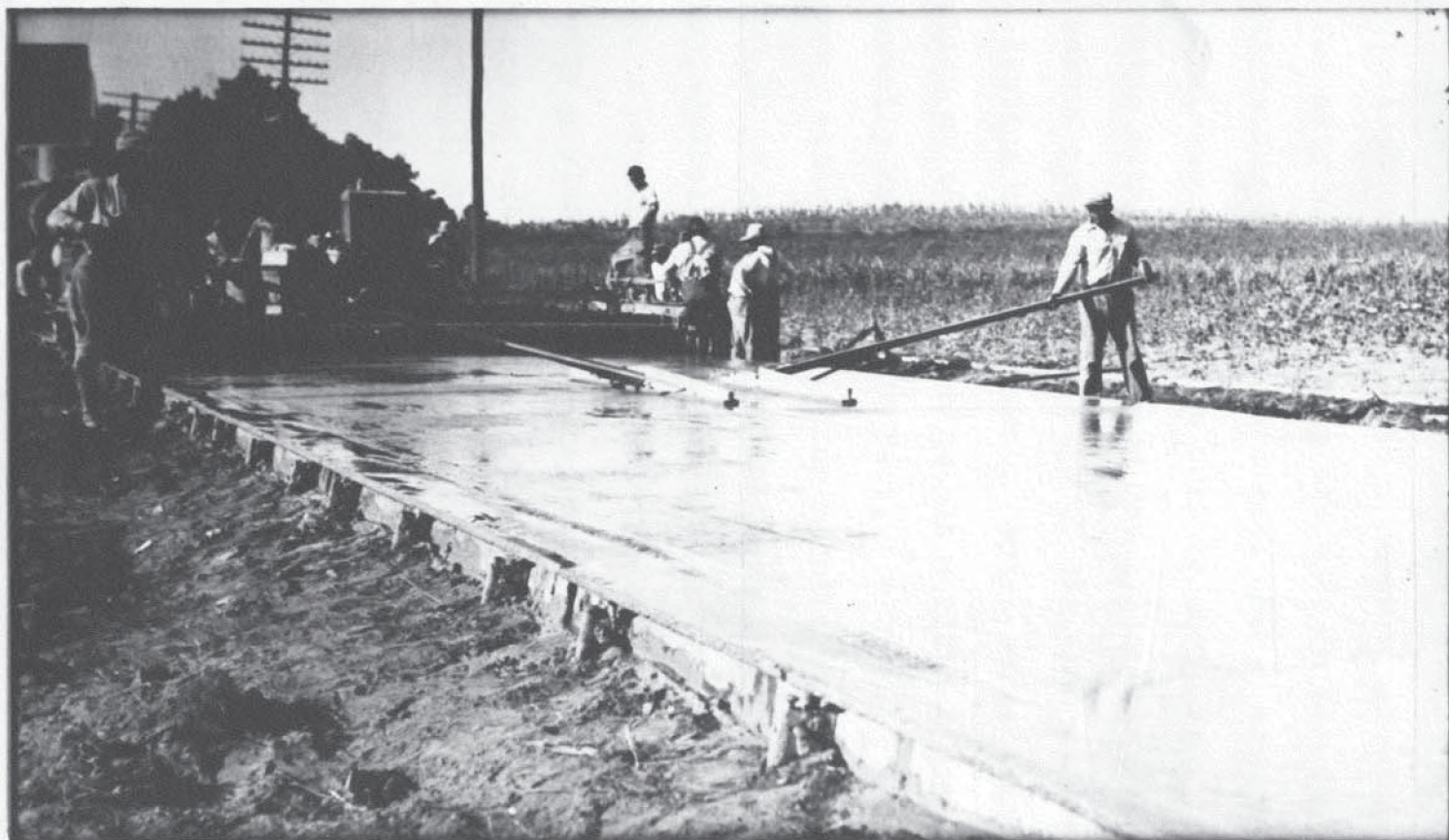
Finishing machines are used on nearly all country road pavements, the few exceptions being in mountainous country where curves and the attendant widened sections make machine finishing impracticable. Finishing machines now have a wide strike-off template which not only gives the concrete its proper contour but consolidates it by pressure. Or there may be two screeds, one to strike-off and one to apply pressure to the surface. The tamping template, common a few years ago, has almost disappeared.

At curves, where highways are widened and super-elevated, the finishing machine may be dispensed with and finishing carried on by hand, because the machines are not able to work on pavements which widen gradually. Some contractors set a false form on widened sections, to serve only as a track for the finishing machine. The additional width is then finished by hand. When that is done, the false form should be removed as soon as possible and the concrete on either side of it be shoveled and sliced



Finishing Machine Follows Directly Behind the Mixer.





Removing Inert Material and Excess Water from Concrete Pavement. This Operation is Carried on Immediately Behind the Finishing Machine.

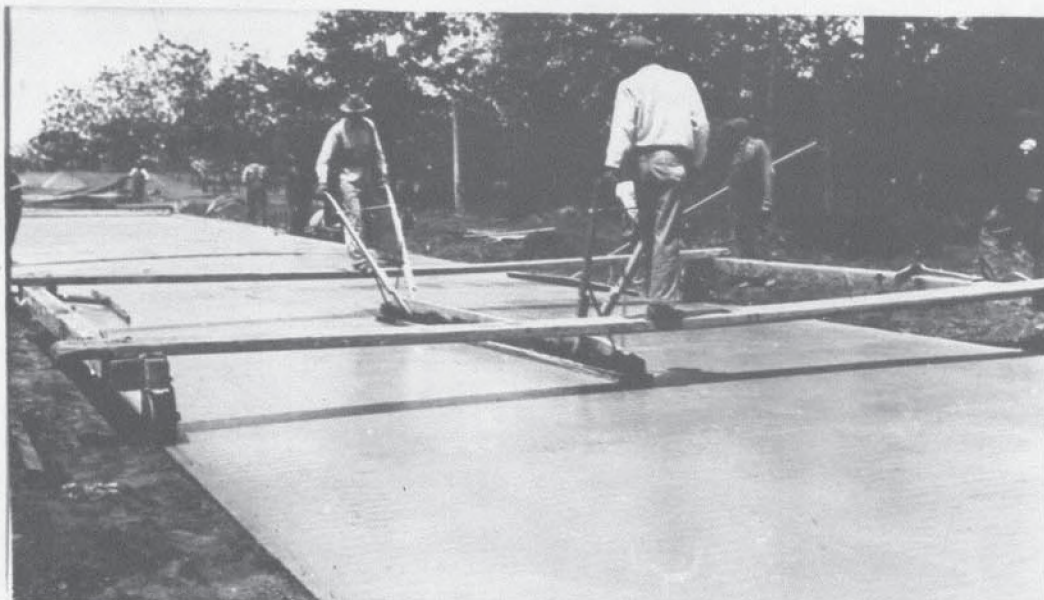


together, else a line of cleavage will exist that will later cause a longitudinal crack.

Finishing machines are not so applicable to city street pavement because of warped crown, variations in width and frequent intersections. They are, however, growing more popular for city work when they are used on the central slabs, and sometimes for the whole pavement. Forms are set at the required distance out from the curb to serve as a track for the finishing machine. Deformed metal plate is welded to this form to make a groove in the edge of the slab and key it to the edge section of the pavement. Spare screeds and shafts are supplied so that the machine has a width range of about 4 feet, usually from 20 to 24 feet.

In many states the finishing machine is followed by a float from 12 to 16 or even 20 feet long, operated with its long axis parallel to the center line of the pavement. It is made of a plank about 3 inches thick and 10 inches wide, stiffened by a plank set on edge, along the top and provided with handles at each end. This longitudinal float, as it is called, is handled by two men, one at each end, who stand on bridges spanning the pavement. It is laid on the pavement at one edge and pulled toward the other edge with a wiping motion, leveling transverse ridges and other high spots and filling depressions.

The longitudinal float is an efficient tool for getting a smooth-riding surface because it operates at right angles to the screeds or belts. If the latter tools leave ridges, they are at right angles to the wheels of vehicles and so give those vehicles the maximum of bump. The longitudinal float eliminates those ridges and any ridges it leaves are



The Longitudinal Float Operates Parrallel to  
The Edge and Wipes Out any Ridges Left  
by the Finishing Machine.



Molding the Raised Edge Curb and Placing the  
Burlap for Curing.

parallel to the wheel tracks and do not produce bumps.

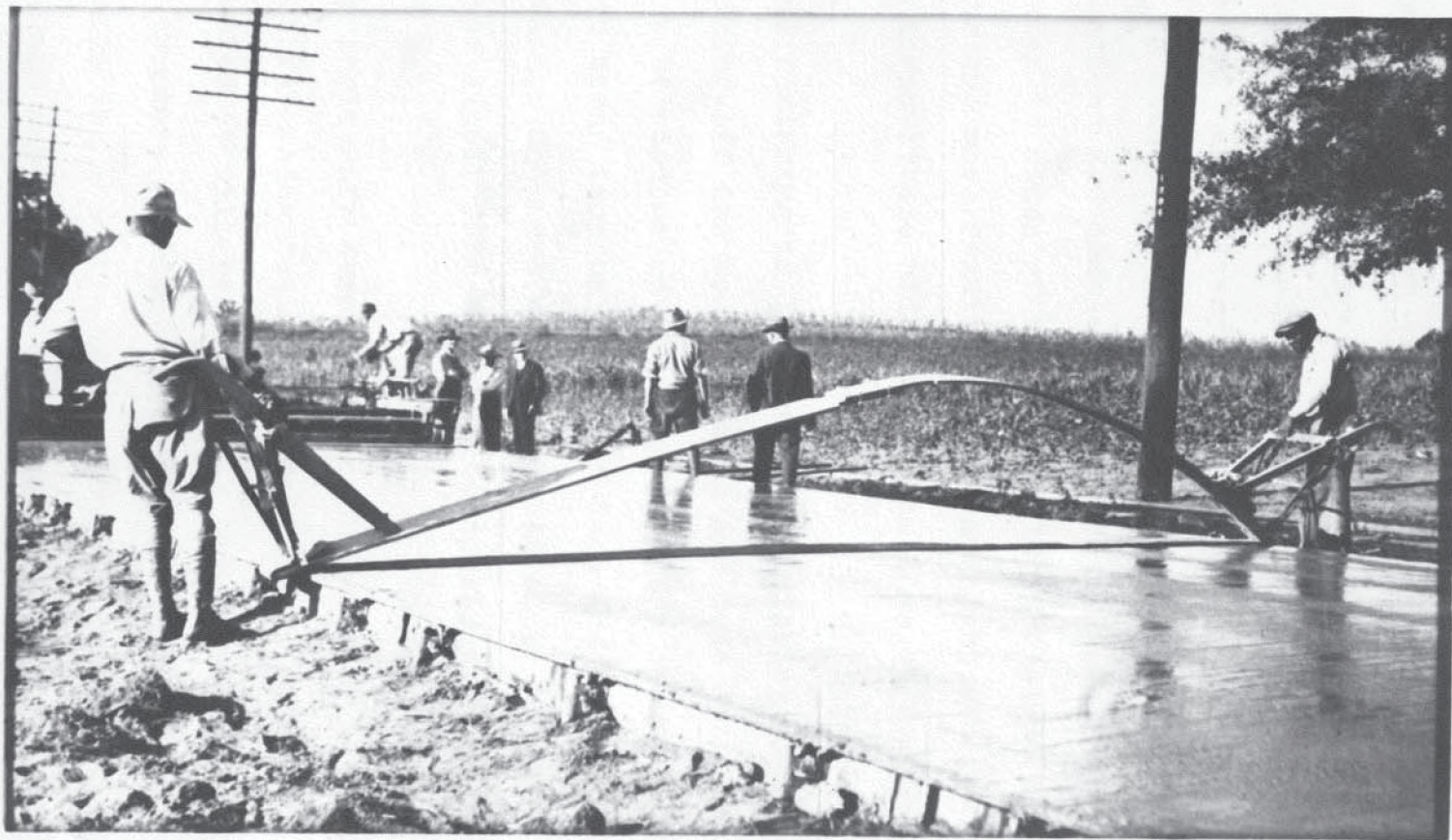
Sometimes two longitudinal floats are used, one as described and the other, which follows it, a lighter, more flexible plank that serves as a belt but is operated in the longitudinal instead of the transverse position.

Following the longitudinal floating excess mortar and laitance are scraped from the surface with a straightedge mounted on a long handle. That is done to remove the thin layer of mortar that sometimes covers the more dense concrete, because it is that layer which is likely to scale off. Scraping also removes the small corrugations not detected by the straight edge and produces a smoother-riding pavement.

The next operation is straightedging. A straightedge about 10 feet long mounted on a long handle is held so that it barely touches the concrete. This is done at intervals of 3 or 4 feet transversely with the straightedge parallel to the center line. Successive straightedging should overlap by  $1/2$  the length of the straightedge. Any high spots discovered are removed and low spots filled. Disturbed places are smoothed with a long handled float and the surface is again straightedged to see that it is now uniformly even.

The final finishing operation is belting, which should be done after the water sheen has disappeared from the concrete. A belt of rubber, fabric, or a thin board, about 10 inches wide and 2 feet longer than the width of the pavement, is laid on the pavement transversely and dragged forward with a sawing motion. The object of belting is the even distribution of the surface mortar and the production of a granular, gritty surface that tires can grip firmly and which will diffuse light





Belting the Concrete.

72  
rays, both during the daytime and at night, making a surface that is readily visible and is not shiny.

A final finish is sometimes given by dragging a strip of burlap, about 3 feet wide, over the surface. That gives a very even, gritty surface and is highly recommended. In some localities the surface is broken up into tiny ridges by brooming. An ordinary street broom, with medium coarse fibers, is attached to a long handle. After the other finishing operations are completed this broom is dragged lightly from center to sides of the slab. It is claimed that broomed pavements are more readily visible at night because the light strikes these little ridges that can then be seen by the driver.

Hand finishing is like machine finishing except that the striking-off and consolidating are done with hand screeds. These are of wood or metal, shaped to the crown of the pavement, shod with strap iron on the lower face and having plow handles on each end. They are usually specified to weigh at least 15 pounds per lineal foot and must be constructed so that they will not sag.

The strike-off template is cut to leave the concrete a little above grade-usually  $1/4$  to  $1/2$  inch - so that after it is compacted it will be at exactly the proper elevation. The tamping template is like the strike-off but is about 4 inches wide and is set a little lower, so that it will strike the concrete and submerge the coarse aggregate.

The tamping template is usually lifted and dropped at one end only until that end has advanced about a foot, when the other end is used in the same manner. Tamping should not

be overdone and in some places is prohibited entirely.

Longitudinal floating, scraping, straightedging and belting follow the strike-off and tamping templates in the same order as for machine finishing, using the same tools in a similar manner.

#### SUMMARY OF FINISHING OPERATIONS.

MACHINE FINISHING	HAND FINISHING.
1. Screed and compress.	1. Screed.
2. Longitudinal Float or Belting.	2. Tamp.
3. Scrape.	3. Longitudinal Float or Hand Float or Belting.
4. Straightedge.	4. Scrape.
5. Correct Surface Float Disturbed Places.	5. Straightedge.
5. Belt.	6. Correct Surface Float' Disturbed Places.
	6. Belt.

Too much tamping, or any over-finishing which brings much mortar to the surface, seems to be responsible for most of the surface scaling, and should be guarded against. Scaling is more prevalent in the states subject to severe frost than in the southern states. In fact, there is practically no scaling south of the Mason-Dixon line.

High joints are a frequent source of annoyance. Every exposed joint should be finished with a float split in the middle to form a space for the joint filler so that the concrete on both sides of the joint can be finished simultaneously. Then it should be carefully checked, with a straightedge notched in the center to form a space for the

94  
protruding joint filler.

All edges of the slab, including both longitudinal and transverse joints, should be rounded with an edger having a radius of  $3/4$  inch. A  $1/4$  or  $1/2$  inch radius is more common, but where tried, the  $3/4$  inch edger has proved especially satisfactory because it eliminated "feathering" and spalling.





This Picture Shows the Various Steps of Finishing From the Mixer  
to The Laying of The Burlap. Note Steel Forms,  
Used Also as Track for Finishing Machine.



## S U R F A C E      C R A C K I N G .

Surface cracking is quite generally called "Hair Checking, but it is believed that the latter term should apply to only one phase of surface cracking and that surface cracks should be classified as follows: (1) Hair Checking or Crazing; minute connected surface cracks which form a pattern with about 120-degree angles between the sides. These frequently do not appear until the concrete has hardened. (2) Surface Checking; cracks which extend for a short distance into the concrete. They are generally short, parallel cracks, often curved, and may run in any direction, but usually point in the direction in which the mixer operated. (3) Cracks which extend through the slab and have been caused by shrinkage of the concrete, movement of the subgrade or disturbance of the concrete before it has hardened.

Hair checking or Crazing is usually confined to the immediate surface and is common where that surface has been over-finished, especially if it has been steel-troweled. It seems to be caused by the shrinkage of the cement paste brought to the surface by troweling and is especially prevalent where water has been sprinkled on the surface of dry mixes to make troweling easier. An excess of water on the surface, causing laitance, too much dust in the aggregates or a dry, hot wind are also causes of crazing. It can be prevented by eliminating the causes and in unhardened concrete can sometimes be cured by belting after the checking takes place.

Surface checking may extend to a depth of an inch or more and is caused by drying of the upper part of the newly laid

94

pavement. This may occur because of an excess of fine material, dry, absorptive aggregate, a dry subgrade, too much water in the concrete, drying winds or failure to sprinkle the pavement as soon as water can be used on it. It can be prevented by eliminating the causes, but the cracks are usually too deep to be cured by late belting. Water may be sprinkled on piles of dry aggregate to prevent the absorption of water from the concrete.

Some subgrades absorb moisture from the concrete, swell and thus crack the unhardened concrete above them. The swelling is often aggravated by rolling, especially if a heavy roller is used. Sprinkling the subgrade 12 to 24 hours in advance so that it is damp for a depth of 3 or 4 inches may relieve the swelling. A layer of sand an inch thick, harrowed into the soil to form a crust, or a layer of waterproof paper between the soil and the concrete, should relieve the difficulty. If the cracks are due to some mechanical disturbance of the concrete they are usually more numerous on the slope of a hill which the mixer descended. They may be caused by the jar of the tamp, by slow flow due to gravity, aided by the shoving action of the strike-off template, or by passing vehicles. They are usually concave in the direction the mixer is operating. More stable forms and drier mixes will help prevent such cracks. A very absorbent aggregate, especially coarse aggregate, will sometimes cause enough shrinkage to make cracks clear through the slab. Preventing absorption by wetting the aggregate before it goes into the mixer is the remedy.

It is general opinion of investigators that surface cracks point toward the mixer because they follow the outline of

batches dropped from the mixer bucket.

In a test of curing methods made by the U. S. Bureau of Public Roads, on slabs 200 feet long, 24 inches wide and 6 inches thick, it was found that one slab, laid on a dry subgrade and not cured, developed 279 local shrinkage cracks, while a slab laid on a wet subgrade and cured with wet burlap and wet earth developed no shrinkage cracks at all.

## C U R I N G .

Curing is the treatment or protection given concrete during the hardening period. Pavements are either air-cured, water-cured, cured with calcium chloride or oxychloride or a surface coating of some waterproof material which prevents evaporation, such as paper, etc.

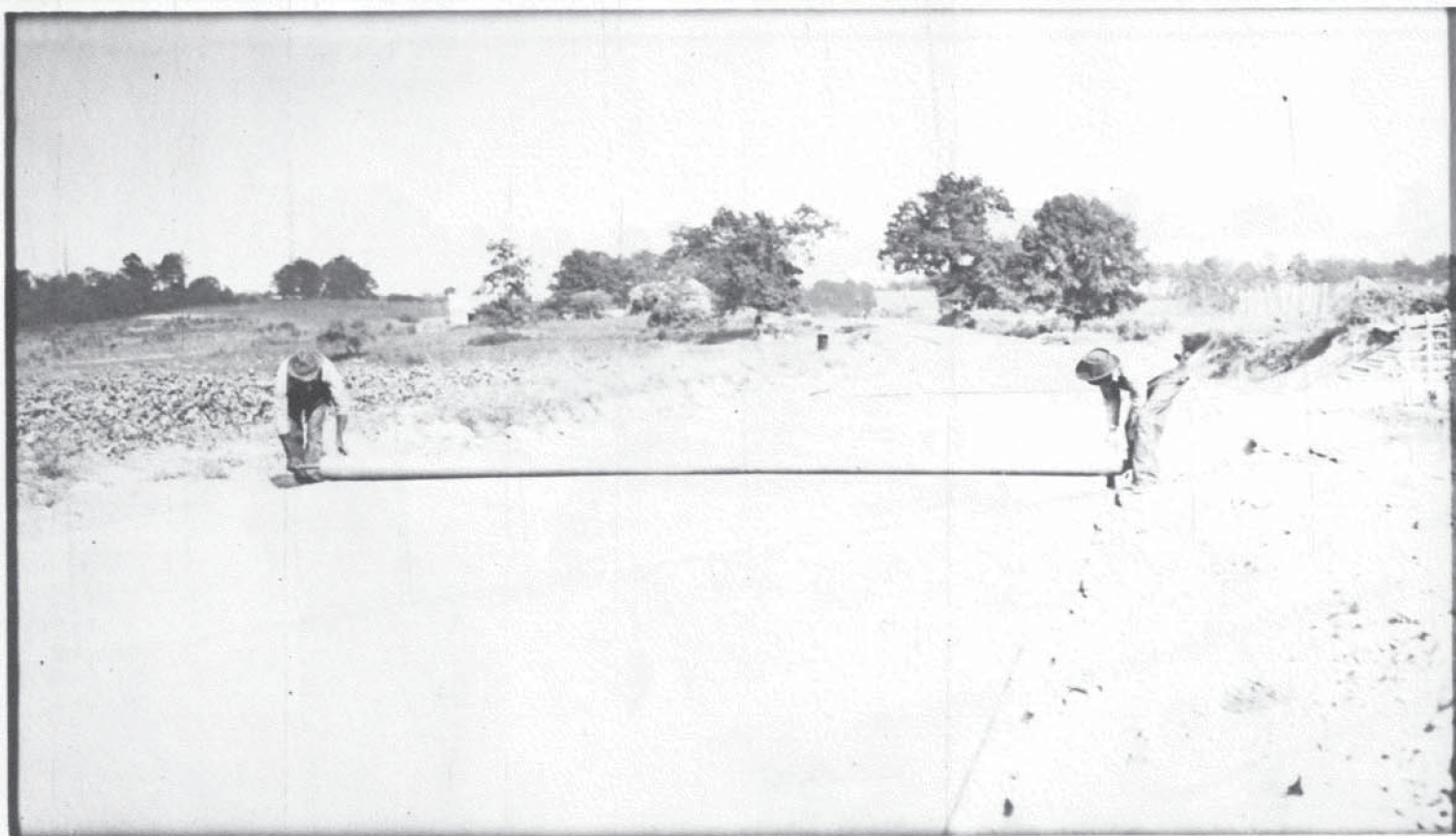
When concrete is mixed it contains sufficient water to hydrate the cement. As soon as it leaves the mixer it begins to loose moisture by evaporation and absorption. In hot, dry, windy weather the comparatively thin slabs used in paving dry out very rapidly. This drying has two effects: (1), there is left insuffucient moisture to complete the hydration of the cement and (2), the concrete shrinks as it dries and tensile strasses are set up while the concrete is too weak to withstand them. The result is a concrete whose strength is only 70 or 80 percent of what it would be, if it had been kept wet, and a slab which is excessively hair checked. When to this drying is added the action of a summer sun, there is produced a chalky, weak, porous surface layer whose resistance to wear is low.

Whatever method of curing is provided, except bituminous coating, a layer of burlap should be put on the slab as soon as it can be done without remarring the concrete. This should be kept wet by frequent sprinkling for several hours, until it can be replaced by the approved curing agent. It is especially important to keep the pavement wet the first few days and the first few hours are the most important of all. Strength lost by lack of moisture during the first few hours



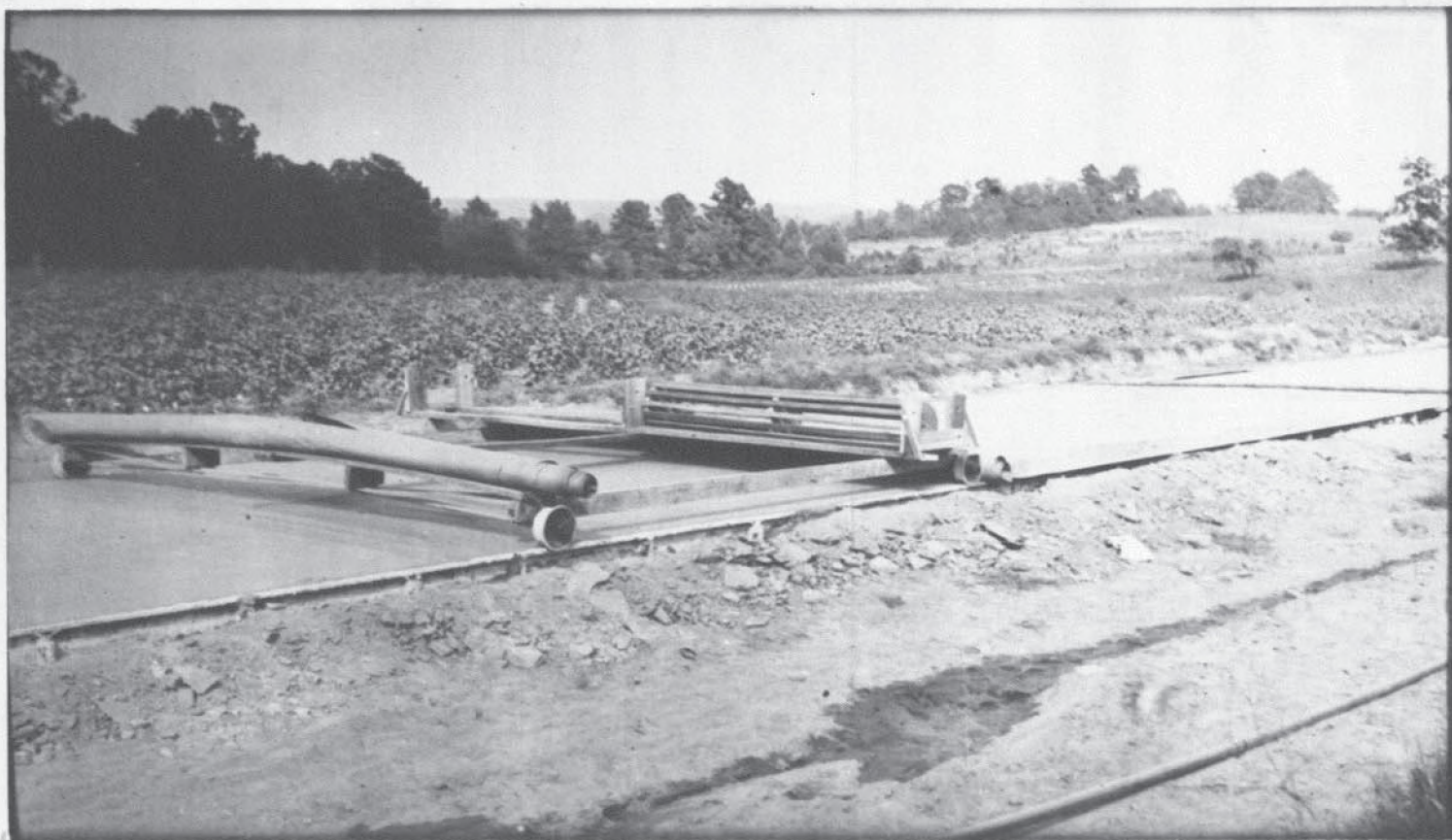
Paper is Used for Curing and Has Proven Highly Satisfactory.  
Heavy Paper is Spread Over Pavement During Curing.





Laying the Paper for Curing.





Carriage Used in Hauling the Rolls of Paper Along the Pavement.  
Note the Forms Used As Tracks.

and days cannot be regained by subsequent curing.

Water curing is the surest and safest. The pavement is kept wet during the early hardening period either by a blanket of earth, hay, straw, by ponds of water held on the surface, by small earth dams, or by continuous sprinkling.. Ponding is only feasible on flat grades and should not be used where the subgrade is a soil that swells much when it absorbs moisture, for if the subgrade swells while the concrete is still green, the slab will be warped and cracked. Sawdust has been used, but should be avoided because it may produce tannic acid, which harms hardning concrete.

Two inches of earth or 6 inches of hay or straw are usually specified. These must be sprinkled frequently so that they keep the slab damp at all times. Hay and straw hold moisture longer than earth. Sand is also satisfactory. Stones have no value for curing. Sprinkling is often more convenient than a wet covering for city streets. Intermittent sprinkling by hand is not advisable because the pavement is then dry most of the time and is cooled too suddenly when sprinkling starts, but a system of automatic sprinklers which keep the concrete wet continuously is satisfactory. A hot pavement should not be cooled suddenly by the application of a considerably quantity of cold water, for the resulting rapid contraction may cause cracking.

Calcium chloride curing was suggested because calcium chloride will absorb moisture from the air, or from any other source with which it comes in contact, until it is itself dissolved. It was thought that a coating of this salt on a pavement would keep the concrete moist by attracting and holding



100

a film of moisture on the surface. This type of curing is not advisable for dry, hot climates.

In recent tests, both an integral mixture and surface coating of calcium chloride proved only slightly better than air curing.

When the material was first used it was found that calcium chloride in excess of 3 pounds per square yard made the concrete "blister" and this type of curing was blamed for some scaling, though it is believed that it was only a contributing factor and not the only cause, except when it was used in excess of 3 pounds per square yard. There was also a tendency to cause a brown stain on the concrete, because the earlier calcium chlorides contained some magnesium chloride, which has since been eliminated. These difficulties with calcium chloride as a surface treatment led to the use of calcium chloride as an admixture. With most cements an admixture of calcium chloride or calcium oxychloride was known to accelerate the hardening of concrete and cause a definite strength "boost" and was adopted to get the strengths ordinarily secured by water curing. Apparently calcium chloride and calcium oxychloride cause a more rapid hydration of cement.

It should always be borne in mind that calcium chloride admixtures do not react similarly with all cements. It must, therefore, only be used after being tested with the cement in question. It must be put into solution before being introduced into the mixer drum.

Calcium oxychloride is not used in solution but is put into the mixer in its dry, powdered form. About 8 percent by weight of the cement is required to produce the same



The Concrete is Covered With Dirt for Curing.  
This is One of Many Methods.



The Finished Product. An Ideal Concrete Pavement.

effect as 2 percent of calcium chloride.

The duration of the curing period depends upon the rapidity with which the concrete hardens. When possible, it should be determined by testing beams or cylinders cured under the same conditions. When no tests are to be made, pavements are usually kept wet 14 days.

Slabs designed by the corner formula should have a modulus of rupture of at least 400 pounds per square inch before they are opened to traffic. That leaves a small factor of safety for impact and fatigue. The latter is neglected because the concrete will have attained its final strength before enough vehicles will use it to cause fatigue, and the former must be guarded against by carefully cleaning the pavement before it is opened. If it is probable that 5-ton trucks will use the pavement as soon as it is opened, or where there is no demand for opening, a modulus of rupture of 500 should be required before vehicles are allowed on it.

## TESTS OF CONCRETE.

Coring has proved an effective method of checking both the depth and quality of concrete and is highly recommended as a means of inducing contractors and inspectors to do good work. Coring machines are used by practically all states and most cities and some commercial testing laboratories also have coring machines.

In general, cores show a wider variation from the average compressive strength than do cylinders from the same job, but some states have secured cores with no wider range in strengths than cylinders.

Some engineering departments have even considered specifying concrete of a given strength and making cores the medium for determining that strength. The principal difficulty is using cores for such a purpose is the necessity of applying a correction to the observed strength because of the variation in height of the cores. Several series of tests have been conducted to determine what correction should be made to make the strength of unusual sized specimens comparable with that of standard 6 by 12 cylinders. There is a reason to believe that erratic results secured from core tests are caused by the slightly curved top and rough bottom, though both ends are capped.

While it is well known that it is not advisable to cast cylinders of small diameter containing large aggregate, the effect of large aggregate on cores is still in doubt.

A marked improvement in the thickness of slabs has usually followed the inauguration of coring.

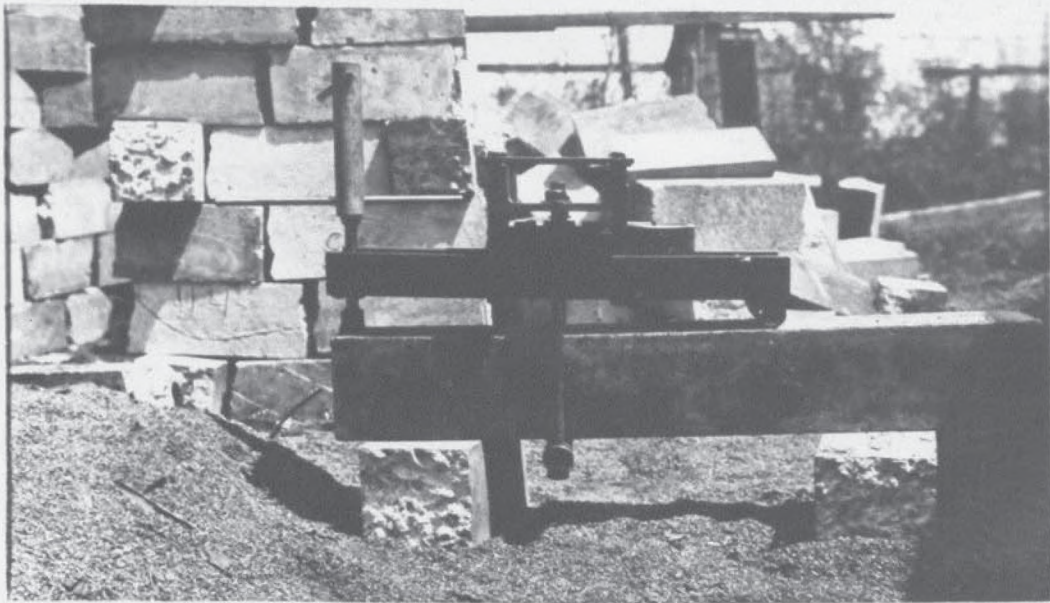
Flexural strength is more important in pavements than compressive strength and, while it has been shown by laboratory investigation that high compressive strengths, usually mean high flexural strengths, a more accurate determination of the flexural strength is desirable. So 6 by 6 by 30-inch beams are being used extensively to test the concrete going into pavements. These are quite generally broken in a small, portable testing machine. Beams are broken as cantilevers and usually two breaks can be made on one beam. It is essential that the clamps holding the beam and the block through which the load is applied can move freely horizontally or the true modulus of rupture will not be secured.

Cantilever tests are not as reliable as the tests of beams having a double support with loads applied at the  $1/3$  points, ordinarily used in laboratory testing because (1), If the cantilever beam does not break exactly over the support, the bending moment is uncertain and (2), That portion of the beam exactly over the support, or very close to it, is the only part tested, while with the  $1/3$  point application of load any weak portion between the points of loading will cause rupture.

There is another factor which must be kept in mind in using the beam test, namely, the possibility of misjudging the quality of concrete since undersanded, honeycombed and porous concrete may show as high strength in flexure as concrete of good quality and higher compressive strength.

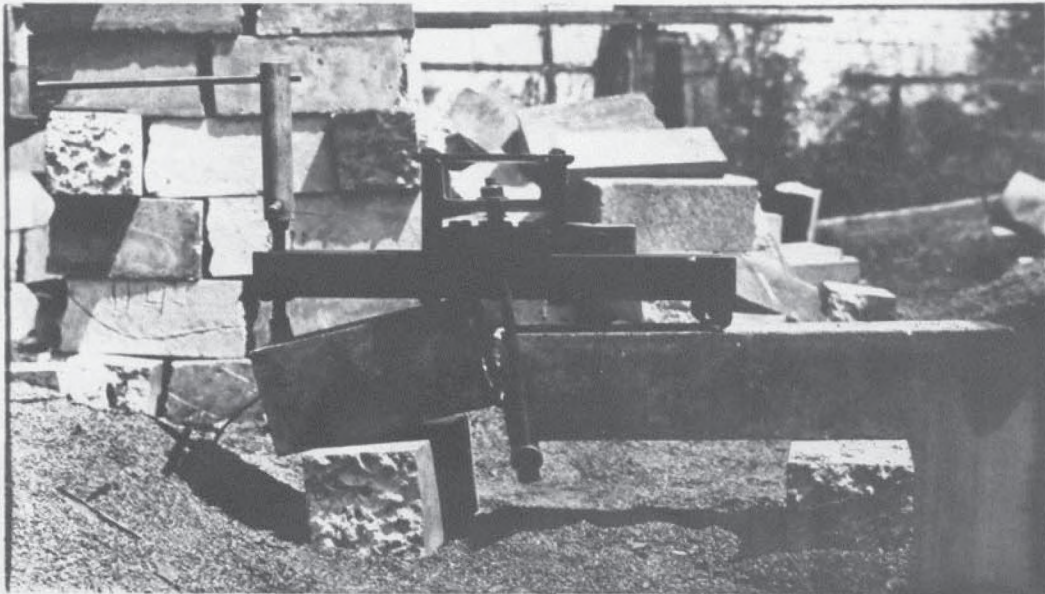
Because it is portable, the beam testing machine has been especially useful where pavements are opened when they have developed a certain flexural strength, for then the machine can be moved along as work progresses, beams can be broken





①

A Portable Beam Testing Machine Used by the Georgia State Highway Department. Showing the Beam in Place to be Tested.



②

The Beam After it Has Yielded to the Stress Put on it by the Tester.

104  
from day to day, and the pavement be opened at the earliest possible moment, without the delay incident to transporting beams to a possibly distant testing laboratory.

In general, for the mixes used for pavement, the flexural strength does not seem to be reduced as rapidly by additional mixing water as does the compressive strength.

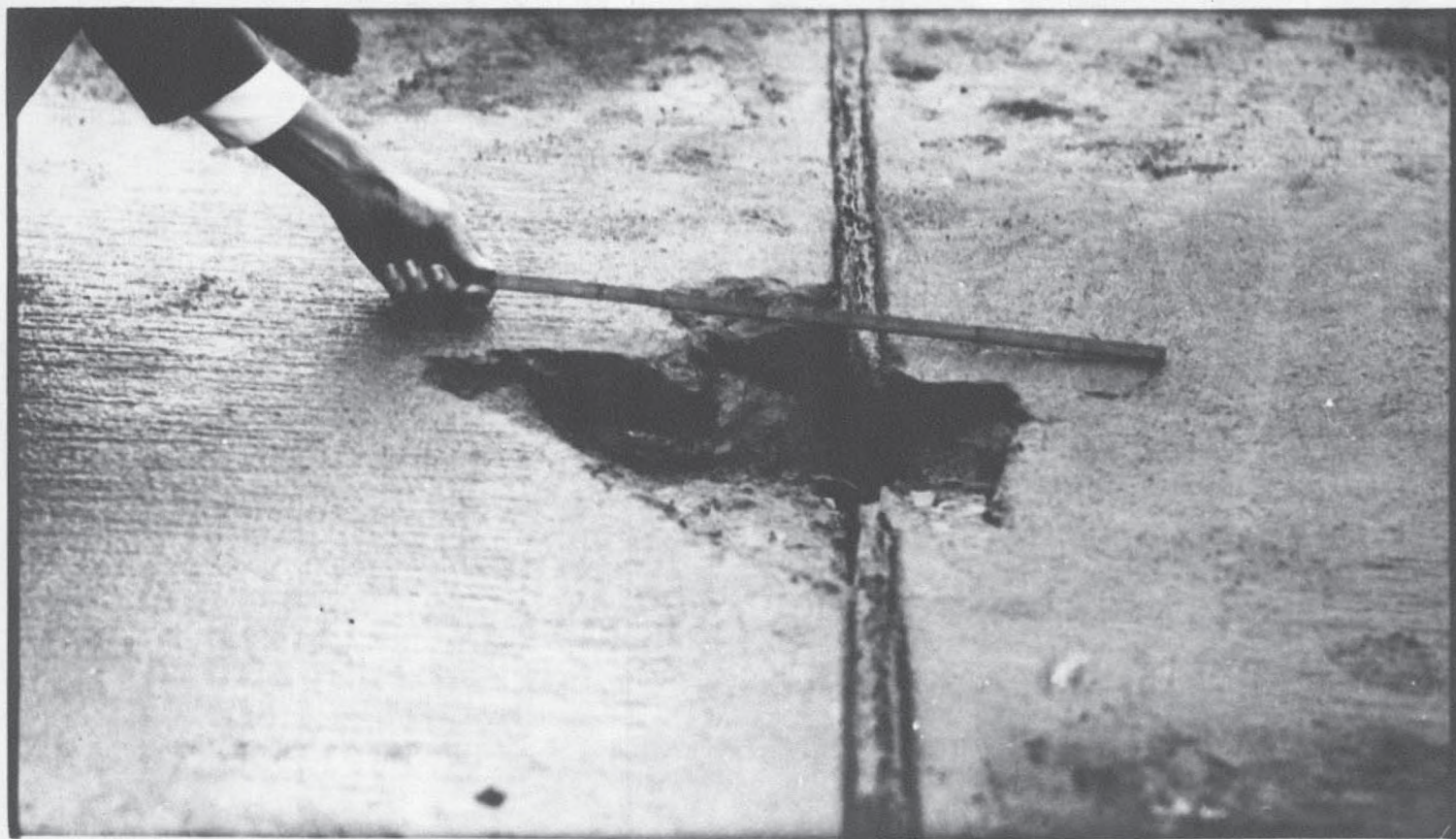
## MAINTENANCE.

There are two phases of maintenances for concrete pavement, filling cracks and joints and replacing slab. The first needs to be done each spring and fall; the second may be required at any time and is largely confined to replacing concrete cut to install underground service pipes.

A bituminous material which will barely flow at 125 degrees F. and will not get brittle at the expected winter temperatures is used for filling cracks. It may be either tar or asphalt. The American Society for Testing Materials give s specifications for asphaltic cement 85-100 penetration, which is suitable for crack filler. An asphalt with lower penetration is used in the warmer climates.

When a job is completed, and each spring and fall thereafter, accumulated dirt should be cleaned from all cracks and joints and they should then be poured full of bitumen. Cleaning may be done with an iron rod with a sharpened hook at the end, with brooms, with the exhause from a truck or with compressed air. After the joint is cleaned it is poured full of bitumen and dry sand is scattered over it. If there is a deep cavity it may have to be filled a second time. The sand prevents blëeding and tracking. A coal scuttle with the spout bent to pour a thin stream makes a good bucket. An enclosed spout will "freeze shut" and give considerable trouble. Joint filler should never be poured in a wide band along the edge of the crack. It does no good there, wastes material, causes impact and is unsightly. If excess filler is scraped





The Lightning was Disastrous to This Portion of Concrete  
Pavement. Note Filler in Transverse Joint.

104

from the surface with a hot shovel, both the appearance and riding quality of the pavement will be greatly improved.

Considerable time and money has been spent in search for a crack filler more nearly the color of concrete, but so far no entirely satisfactory substitute for bitumen has been developed.

Patches can be made which cannot be distinguished from the rest of the slab. This requires a dry concrete, which will shrink very little, and intermittent tamping at 15-minute intervals, to maintain contact between the new and old concrete as shrinkage occurs.

The first consideration in making a permanent, invisible patch is a subgrade which will not settle. If the patch is over a trench, the concrete slab can be cut wider than the trench so that there will be a 5 or 6 inch shoulder of undisturbed earth under each edge of the patch. It is also good practice to extend the patch below and a little way under the edges of the old slab to help support those edges. The edges of the old slab should be trimmed so that the top 2 inches is nearly vertical to eliminate the possibility of "fins" which soon spall.

The mixture to be used in patching depends upon the time the patch is to be kept closed to traffic. Ordinarily it is desired to have the pavement opened to traffic quickly, so a high early strength mixture is needed. (Will be discussed further on). Whatever the mixture selected the water content should be such that the mortar will barely stick together when squeezed in the hand and no water comes to the surface under the repeated tamping.

107

This dry mixture is shoveled into the hold to be patched and is thoroughly rammed. The tamp used along the edges should have a small area - the end of a 2 by 4 scantling makes a good tamp and the fresh concrete should be forced close against the old slab. This is repeated three or four times at 15 minute intervals, so that separation of old and new concrete, as the concrete shrinks during drying and hardening, will be prevented. A 2 by 12 plank laid flat on the patch, with the ends resting on the old slab, struck with an ordinary 12-pound sidewalk tamp, compresses the concrete evenly and assures a surface at the same elevation as the old slab. Then the surface is struck off, with a straightedge which rests on the old slab, and finished with a wooden float. If belt marks are prominent on the old pavement, belting the patch will make it still less visible. It is not at all difficult to make patches which can only be detected after a careful search.

Depressions caused by settlement can be leveled up by resurfacing the low portion. If a 3-inch layer would be required, the resurfacing material should be concrete, applied to the roughened slab by the methods described under "Resurfacing." The edges of such a patch should always be vertical. For very shallow depressions either hot or cold patch asphalt can be applied. For hot patching, the depression is first filled with dry stones of from 1/2 to 1-1/2 inch grading (or less, depending on depth of depression). Hot asphaltic cement with a penetration at least ten points less than is used for asphaltic concrete in the same district is poured over these stones, then hot stone screenings are scattered

over them, asphalt is poured over the screenings, and ironed out with a hot iron. Unless asphalt of low penetration is used, the patch will be so much softer than the adjoining concrete that it will pound out under impact. High penetration to prevent cracking is not needed for patches. A straightedge resting on the unpatched portion of the slab should be used to bring the patch to exactly the proper elevation.

Cold patch is a mixture of asphalt, sand and stone, made up in advance and tamped, cold, into the depression. It solidifies when the lighter oils it contains evaporate. It is not as satisfactory as hot patch.

Asphalt patches in a concrete slab are usually not as permanent as the concrete, detract from its appearance, and should be avoided when possible.

Slabs which have settled can be raised and the subgrade tamped back under them. To do this a trench is cut beneath the slab large enough to permit the installation and operation of jacks. Then the pavement is jacked up to a little above its proper height and the earth is tamped in to hold it in position. Often the space into which the earth is to be tamped is too small to permit good tamping. Then it can best be filled with a 1-12 damp cement-sand mortar worked into place with a log chain or heavy wire cable. The chain is stretched under the pavement and the mortar is worked up under the slab by sawing the chain back and forth. The cement is put in to make the foundation solid without tamping and to hold the sand in place. This method is only applicable to comparatively narrow slabs.

The riding quality of old roads, built with high joints, can be greatly improved at moderate cost by bush-hammering or grinding off the high spots.

## HIGH EARLY STRENGTH CONCRETE .

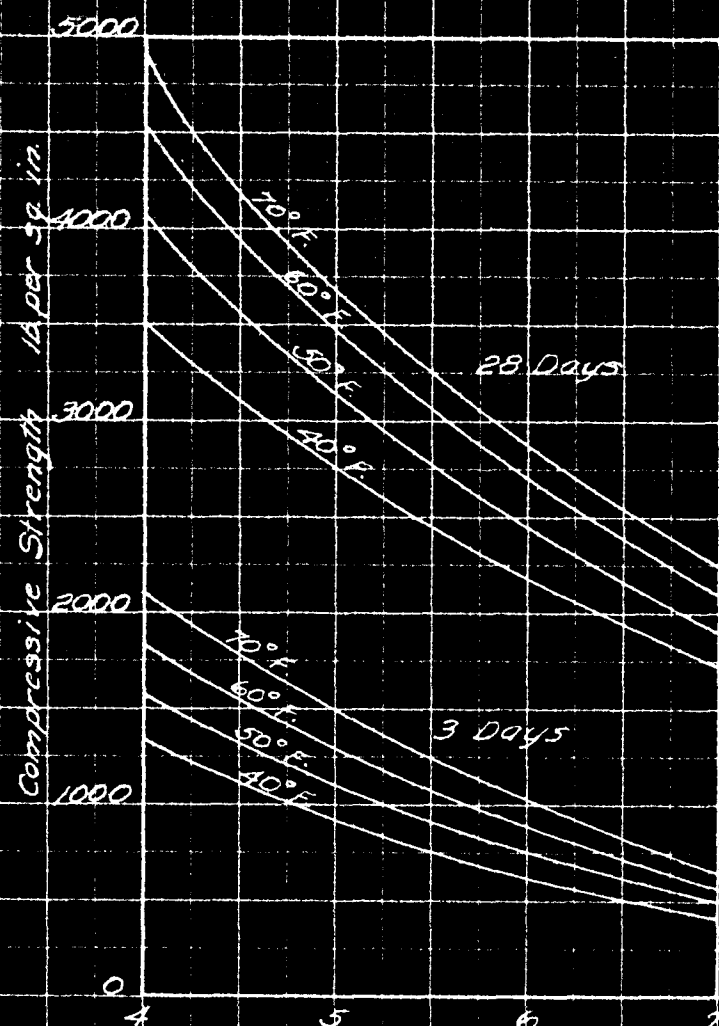
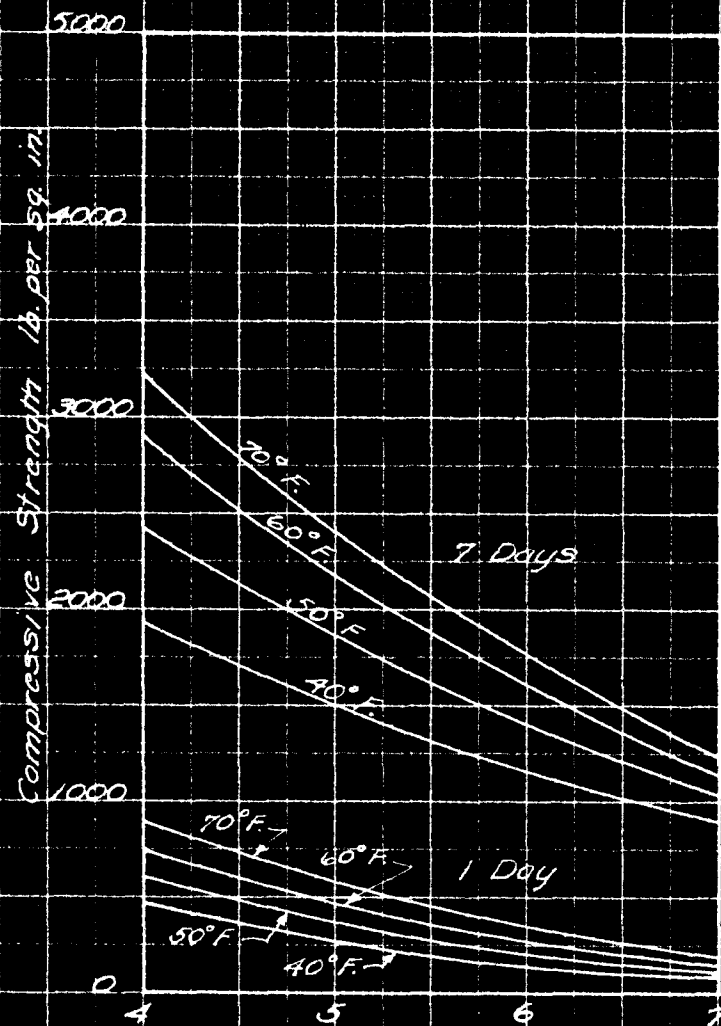
High early strength concrete is often desirable at important intersections and for patching. The small extra cost is also justified for important thoroughfares which must be opened as soon as possible. High early strength concrete is made with standard cement by using a richer mixture, longer mixing time and lower water-cement ratio is considered economical for ordinary pavement work.

In general each factor in the 28-day strength of concrete improves the early strength to a more pronounced degree. Obviously, then, high early strength concrete, using standard cement, requires the same precautions as a higher quality of 28-day concrete. The most important factor in this increase in strength is a reduction in the quantity of water per sack of cement. Whether accomplished by increasing the quantity of cement or by decreasing the quantity of water, the principle is the same. In general, both are necessary.

The importance of having plastic mixtures and proper curing must not be overlooked. Low water ratios should not be attempted at the sacrifice of workability. The mixes must be plastic enough to place properly, without honeycombing, and sufficiently workable to make possible a smooth-riding surface.

Temperature plays an important part in the strength of concrete at any age of test, but especially at the earlier ages. If the existing temperature is below 70° F., appreciable benefits may be derived from supplying heat to the aggregates and water, and by preventing the radiation of heat from the





Water-Cement-Ratio U.S. Gallons per sack

CURVES SHOWING THE EFFECT OF AGE AND TEMPERATURE ON THE COMPRESSIVE STRENGTH OF CONCRETE OF VARIOUS WATER-RATIOS

Fig. 11

110

finished slab. The early strength will be increased by higher temperatures than 70° up to about 120°. Temperatures over 120° may reduce the strength.

Figure 11 shows the relation between the compressive strength of concrete when cured damp and the quantity of mixing water at four ages for different temperatures of curing. The data for 70 degrees Fahrenheit are from tests, using average materials and following standard methods of test of the American Society for Testing Materials. The data for the other temperatures were deducted from these by means of the relative compressive strengths at different temperatures reported in "Influence of Temperature on the Strength of Concrete," by A. B. McDaniel.

It may be seen from the diagram that if 2000-pound concrete is required at 3 days, it can be secured by using a water-cement ratio of 4-1/4 gallons per sack of cement and curing at 70 degrees F.; the corresponding strengths at the other ages are about 700 pounds at 1 day, 3000 pounds at 7 days, and 4600 pounds at 28 days.

The diagram also shows how the effect of low curing temperature may be offset by use of less mixing water. For example, if 1000-pound concrete is desired at 3 days, it may be secured by using a 6 gallons of water per sack of cement and curing at 70 degrees F., or at lower curing temperatures by using the following quantities of water: 5-3/4 gallons and curing at 60 degrees F.; 5-1/4 gallons at 50 degrees F.; and 4-7/8 gallons at 40 degrees F. It must be borne in mind that when using these lower quantities of mixing water per sack of cement, more cement will be required to produce

concrete of a given consistency or condition of workability.

From the foregoing it is evident that in cold weather the cement requirement for concrete may be maintained at a minimum by heating the materials and by curing at the higher temperatures. When high early strengths are required, a combination of low water-cement ratio and normal curing temperature will produce the best results.

For concrete cured at normal temperature, increasing the mixing time from 1 to 2 minutes will add about 100 pounds per square inch to the strength at 3 days, and increasing the mixing time from 1 to 5 minutes will add about 200 pounds per square inch. The additions to the 1-day strength will be about half of these amounts.

F I N I S .

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Fine Example of Finished Pavement.